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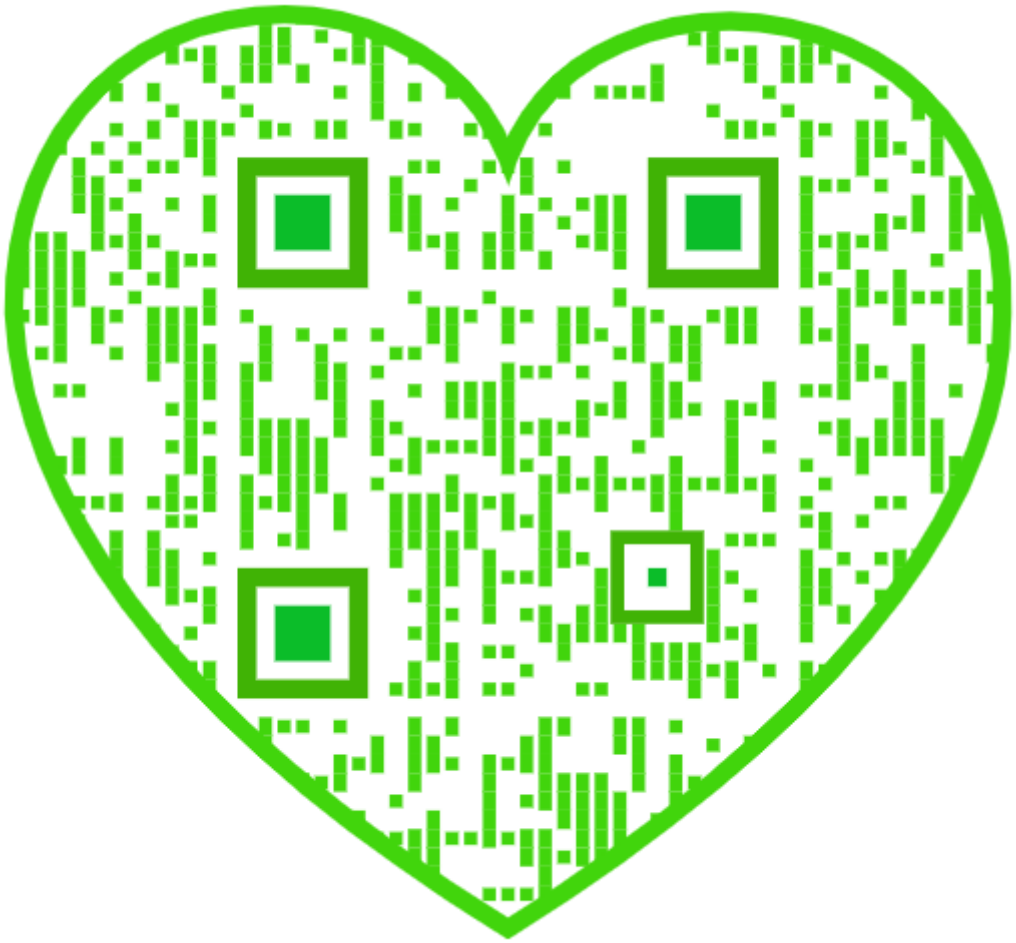

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THE ELEMENTS OF BOTANY

BY

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WITH ILLUSTRATIONS

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PREFACE.

THE Elements of Botany appeared in 1895, and with a few alterations was stereotyped in the following year. I take the present opportunity of correcting one or two obscurities or mistakes. If the book could have been rewritten it might have been advisable to introduce the conception of the *stele*, which helps to make clear the identity of the central vascular cylinders of the Dicotyledonous stem and root—a point in which the older terminology is less effective. For this purpose it is allowable to define the stele as a group of tissues characterised by the predominance of conducting elements and contained within an *endodermis*. Used in this sense the word *stele* also coordinates the vascular anatomy of the Dicotyledon with that of the fern-rhizome, whereas the term *vascular bundle*, used in these instances, may confuse the beginner. It seems to me that broad resemblances between different types of vascular arrangement are to the elementary

student of greater value than fine distinctions, and that a more elaborate view of the stele may be deferred until he has more knowledge of plant anatomy.

As this book originally appeared, the description of the germination of the bean contained a blunder which is now set right. I am indebted to Mr Heber Smith[1] for pointing out that the part played by the micropyle, in the emergence of the radicle, is often wrongly given. I regret that I have not room in the text for a fuller account of the process such as is supplied by Mr Heber Smith's letter.

The substance of the book was given in the form of lectures on Elementary Biology to Cambridge students. This—the Botanical course for medical students—is now given by Mr F. F. Blackman, who has introduced certain improvements, notably in the addition of *Fucus* as a type of reproduction. But I think it will be found that whatever value my little book had as an introduction to the study of plants, it retains in relation to Mr Blackman's course of instruction.

Except where otherwise specified, the illustrations have been drawn from nature by Miss D. F. M. Pertz, and by Dr W. G. P. Ellis, formerly Demonstrator in

[1] *Nature*, Feb. 4, 1909.

Botany, to both of whom I desire to express my sincere thanks. Dr Ellis not only undertook the chief part of the drawings, but has also aided me in other ways in the kindest manner. I am particularly indebted to him for valuable help in the selection of laboratory material, and for the arrangement of the Appendix containing instructions for practical work.

To Mr Shipley, the Editor of the *Cambridge Natural Science Manuals*, I am indebted for much kindly co-operation.

FRANCIS DARWIN.

Botany School, Cambridge.
January, 1910.

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"I conceive it is a fine study and worthy a gentleman to be a good botanique, that so he may know the nature of all herbs and plants, being our fellow creatures."

The Life of Edward, Lord Herbert of Cherbury, written by himself.

CHAPTER I.

YEAST — REPRODUCTION — NUTRITION — FERMENTATION — SPIROGYRA — NUTRITION — TRADESCANTIA-HAIR — CELL OF ELODEA-LEAF — CELL OF THE PITH OF ELDER.

YEAST is familiar as the cause of the process known as fermentation, by which alcohol is produced from sugar.

It is obtained from the brewers for use in the laboratory as a muddy brown fluid. The muddiness depends on the same general cause that gives turbidity to dirty water, namely the presence of innumerable very minute particles suspended in the fluid. In the case of yeast each of these particles is a simply organised plant belonging to the great tribe of Fungi, and known as *Saccharomyces cerevisiæ*.

The plant is of the simplest possible structure, since it consists of a single cell: it has nevertheless the attributes of a more highly organised plant, it leads an individual existence and is able to feed, to grow, and to reproduce itself.

The yeast cell, like those which build up the tissues of more complex plant-bodies, consists of a mass of protoplasm surrounded by a cell-wall. It is possible to make

the cell-wall separate from the protoplasm by pressure applied to the cover-glass of a mounted preparation. The protoplasm is squeezed out of the broken cell (just as the flesh may be squeezed out of a grape-skin) and the torn empty walls and crushed fragments of protoplasm remain.

The cell-wall is a colourless membrane made of a substance called *cellulose*. Cellulose is a compound of the greatest importance in plant-physiology. It forms a large proportion of the substance of plants, and is the basis of many products of vegetable origin. Cotton wool, which is made from the hairs on the seeds of the cotton-plant is nearly pure cellulose, and the same is true of filter-paper which is manufactured from vegetable cell-walls.

In a wooden match are many thousands of cells of which the walls are cellulose[1]. If such a piece of wood is dipped in strong sulphuric acid or is charred by fire a mass of charcoal is the result. This fact proves that cellulose contains carbon, and as a matter of fact carbon makes up nearly half the weight of this substance.

Cellulose also contains hydrogen and oxygen in the proportion in which they exist in water, its formula being $C_6H_{10}O_5$. This is the same formula as that of starch,—an important fact, as will appear later on. In spite of the identity of formula the two substances have not identical reactions. Starch is characterised by giving a blue or purple colour with iodine. Cellulose is characterised by not giving this test unless it has been previously treated with acid. In the laboratory it is usual to shorten the process by the use of an acid preparation of iodine. The

[1] More accurately lignified cellulose.

purple colour given by this—Schulze's fluid—is characteristic of cellulose. This reaction must be studied on the cell-walls of the higher plants, because the cellulose of the yeast plant, in common with that of the fungi generally, only gives a purple colour after a certain preliminary treatment.

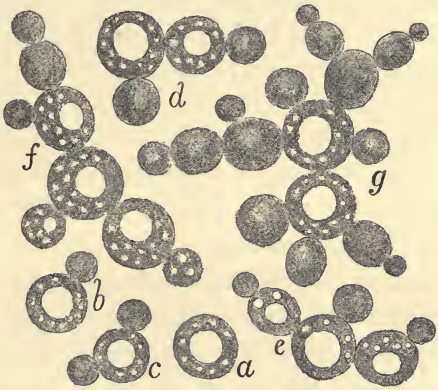


FIG. 1.

YEAST UNDER A HIGH POWER,
a—g successive stages of budding.

The yeast-cell as it appears under a high power of the microscope is shown in fig. 1 *a*. The cells are seen to contain a granular protoplasm in which clear spaces occur: these are cavities in the protoplasm, containing fluid and known as *vacuoles:* the fluid in the vacuoles is known as *cell-sap.*

Reproduction.

The fact that yeast increases in quantity by reproduction can be demonstrated by adding a minute drop of the

yeast-containing fluid to a dilute solution of sugar in spring water. The increase of the organism is visible by the increased turbidity of the culture-fluid. With the microscope it can be seen that the increase is due to a process of budding, as shown in fig. 1. The cells begin to bulge or swell in places and the buds so formed break off and begin an independent life. They may however remain attached for some time, and by a series of buds give rise to the chains of cells shown in the figure[1].

Nutrition.

When a small number of yeast plants increase so as to alter the appearance of the fluid in which they float, the fact that a quantity of new protoplasm and new cellulose has come into being forces itself on the observer; and the question whence and how it has arisen must be met. When an organism grows, the new organic material built on to the old body comes from the food supplied. The food diminishes, while the organism increases; one turns into the other literally, and absolutely. Nearly half the dry weight of cellulose is carbon, it is certain therefore that the yeast has been supplied with carbon in some form in which it can be used as food. In the laboratory carbon is given to yeast in the form of sugar[2]: and if two jars are prepared one (i) with, the other (ii) without, sugar, it will be found that yeast increases rapidly in (i) but not in (ii). In a similar way it can be shown that the increase in the

[1] Another form of reproduction occurs in yeast; it is not described because it is not met with in ordinary cultures.

[2] The formula of Cane Sugar is $C_{12}H_{22}O_{11}$, of Grape Sugar $C_6H_{12}O_6$.

amount of yeast does not simply depend on the sugar, but also on the presence of certain other substances which must be supplied to the plant in solution. The reason is obvious: the cells contain nitrogen, sulphur, phosphorus, potassium, lime and magnesium, and these must be supplied in the culture-fluid. The solution used for the growth of yeast is known as Pasteur's solution and has the following constitution[1]:

Potassium phosphate	20 parts
Calcium phosphate	2 „
Magnesium sulphate	2 „
Ammonium tartrate	100 „
Cane sugar	1500 „
Water	8376 „
	10000 parts.

The two chief points to notice are the conditions in which carbon and nitrogen are supplied to the plant. Carbon is supplied as sugar and the yeast-cell cannot assimilate carbon unless it is presented to it in an organic compound. Yeast therefore resembles animals in regard to its carbon supply, since like an animal it depends on a substance (such as sugar) which has been manufactured in the leaves of another plant, the sugar-cane.

But in regard to nitrogen the yeast differs from animals: no animal could live if its only nitrogenous food were an ammonia compound, whereas the yeast is able to make use of the ammonium-tartrate.

[1] *Practical Biology* (Huxley and Martin), 1888.

Fermentation.

In the process of fermentation, sugar is broken up into CO_2 and alcohol: the bubbles of gas become entangled in the sugary fluid and give rise to the scum on the surface so characteristic of fermenting fluids. Small quantities of glycerine and of succinic acid are also produced.

It is easy to show that fermentation depends on the life of the yeast-cell, for the process can be stopped by boiling (and therefore killing) the plant. Into the difficult question of the nature of fermentation and its relation to respiration and to the source of energy generally I do not propose to enter.

Spirogyra.

Spirogyra is a fresh-water weed, a representative of the Algæ, the great tribe to which the sea-weeds also belong. It occurs in slimy tufts of delicate bright green threads. Each thread is a Spirogyra plant which, although more elaborate in structure than yeast, is yet of a very simple construction, consisting as it does of a row of cells united end to end. Each cell is precisely like its neighbours, there is no division of labour, each cell being responsible for its own nutrition, each growing independently of the others, and each being capable of taking the same share in reproduction. When one of the constituent cells of Spirogyra has grown to a certain length it becomes partitioned into two cells by the growth of a new transverse wall. This process is called *cell-division*, and it will appear later that it is of paramount importance in the development of plants generally. It is important to

notice that cell-division in this sense does not necessarily mean that the cell is actually split into two free halves: in the case of Spirogyra, and in growing plants generally, the original cell is simply divided into two compartments which increase in size and may again divide. It follows from this manner of growth that a Spirogyra as it grows comes to consist of more and more cells.

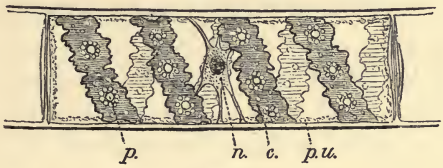


FIG. 2.

A CELL OF SPIROGYRA.

c, the spirally wound chloroplast.
p. u, the protoplasm lining the cell (*primordial utricle*).
n, the nucleus suspended by protoplasmic ropes.
p, a pyrenoid with numerous small starch grains.

Each compartment of the plant is a good example of the perfect vegetable cell. It has a cellulose wall often coated outside with a layer of slimy material; the cavity of the cell is lined with a coating of protoplasm, inside which is a large vacuole taking up nearly all the room inside the cell. The fluid in the cell cavity is called *cell-sap*, and is a very dilute solution containing certain salts, vegetable acids, sugar and tannin. In the protoplasm a certain part is differentiated from the rest into what is called a *chloroplast*—that is to say a piece of protoplasm coloured green with the substance *chlorophyll*. When a green leaf or a Spirogyra plant is put into spirit or ether it becomes colourless because the chloro-

phyll is soluble in these fluids. It is important to remember the difference between chlorophyll, a substance soluble in alcohol, and a chlorophyll-body or chloroplast, which is a special kind of protoplasm. In Spirogyra the chloroplasts are of a remarkable spiral form, winding like corkscrews round the cell, as shown in fig. 2. It is the spiral arrangement which has given the name Spirogyra to the plant.

In the cell-cavity is another organ, the *nucleus*, a part of the protoplasm, denser and staining more easily than the rest of the protoplasm, and having certain functions which need not be discussed. It is suspended in the cell cavity by ropes of ordinary protoplasm. The nucleus contains one or more small bodies, the *nucleoli*.

The treatment of Spirogyra with glycerine or strong salt solution is recommended in the *Practical Work* in order to illustrate an important fact, namely that the cell is tensely filled with cell-sap, the protoplasmic lining being blown out with cell-sap, as an air-cushion is blown out with air. The glycerine or strong salt solution takes away some of the water from the cell-sap and the protoplasmic lining collapses. The importance of this observation will appear later on, in a section devoted to the stability of plant structures.

Nutrition.

Since the Spirogyra increases in substance in the water in which it grows it is quite certain that this water must contain the food materials which are transformed into new protoplasm and new cell-walls. If the water be analysed it will be found to contain in minute quantities lime,

potassium, magnesium, iron,—in fact the necessary mineral constituents of the food. Nitrogen will be supplied as a nitrate, sulphur as a sulphate, phosphorus as phosphate. The water will not however be found to contain sugar or any substance from which fungi can obtain carbon. It is therefore clear that Spirogyra has some special method of assimilating carbon. It is in the way that it gets its carbon that Spirogyra (and all other green plants) differ in nutrition, not only from fungi, but also from animals. To yeast as to animals CO_2 is an absolutely waste product, cast out in the process of respiration as of no more use. But to the green plant it serves as an indispensable food-supply, and it is because the ditch-water contains CO_2 in solution, that the Spirogyra is able to live in it. The process by which the carbon is taken out of the CO_2 and built into living substance is known as the *assimilation* of carbon.

The fact that CO_2 serves as food may be proved by observing the results of depriving green plants of this gas. If a Spirogyra or other chlorophyll-containing aquatic plant is cultivated in water, which except for the absence of CO_2 is precisely like that in which it naturally lives, the plant dies. This experiment alone is not conclusive as to the cause of death, but the conclusion is strengthened by the result of another experiment. If sugar is added to the water the plants do not die: from this it would be rational to suspect that the absence of CO_2 in the first experiment was injurious because it meant the absence of carbon-containing food-stuff. Death is not the only test of an organism being starved: if an

animal is deprived of food, the degree to which it suffers from the deprivation can be roughly gauged by estimating the amount of fat in its body. When the degree of starvation is severe the amount of fat is small. In a green plant starvation may in the same way be estimated by the amount which it contains of another carbon-compound, namely starch. By applying this test it is found that in water containing no CO_2 the Spirogyra soon loses its starch, which reappears when CO_2 is added to the water.

The same tests are of value in determining the conditions under which assimilation of carbon from CO_2 can be carried on. Thus no green plant can live permanently in darkness. Even dull light is injurious, as may be seen in the dwarfed miserable appearance of shrubs, etc. growing in deep shade as compared with specimens in brighter light. Here again the starch test is of value. If a green plant is placed in the dark it soon loses the starch it possessed, even though the water in which it lives contains CO_2: and the starch will not re-appear until the plant is once more exposed to light.

On the other hand a green plant can feed on sugar in darkness, so that light seems to be a condition especially connected with the extraction of carbon from CO_2. The fact is that the chloroplasts which give the green colour to plants are machines, the motive power of which is the energy of light, and whose special quality is the power of robbing CO_2 of its carbon.

It is easily proved that this power resides in the chloroplasts. In the leaves of variegated plants are

certain patches or stripes which are yellowish-white instead of being green, because they contain no chlorophyll. If such a plant is placed in the dark the leaves will after a time become starchless; if it is then exposed to light, starch will appear, but only in the green parts where chlorophyll is present. Moreover it is possible with the help of the microscope to see that it is *in* the chloroplast that the starch appears and disappears. This is especially evident in Spirogyra, where the starch in the form of minute granules is gathered round certain centres in the chloroplasts which are known as *pyrenoids.*

The fact that the green plant is a machine driven by the energy of sunlight can be made evident to the eye by a well-known observation. When a water-plant, such as the common river-weed *Elodea,* is placed in a beaker of spring-water and exposed to sunshine, streams of minute bubbles are seen to issue from the cut stalks. If the beaker is darkened the bubbles cease and the same thing happens if the water is freed from CO_2. The bubbles contain the oxygen that is set free in the process of assimilation: it may roughly be said that the plant seizes the carbon from the CO_2 and lets the oxygen go. It is obvious therefore that if there is no CO_2 in the water the production of oxygen must cease, and the fact that the bubbling stops in the dark shows that light is the power which drives the machine. The stream of bubbles pouring from a water weed in sunlight is, like the smoke coming from the chimney of a cotton-mill, a sign of internal activity. The chimney ceasing to smoke may mean either that there is a want of cotton, a want of coal, or that the machinery is broken.

In the same way the plant may cease to bubble for want of raw material (CO_2) or for want of driving power (sunshine) or because the machinery is broken, i.e. the chlorophyll-bodies killed.

Tradescantia, Elodea, Elder.

The present chapter is intended to give a somewhat wider introduction to anatomy and physiology of the plant-cell than can be obtained from a study of yeast and Spirogyra. Parts of certain higher plants have therefore been included in the *Practical Work*.

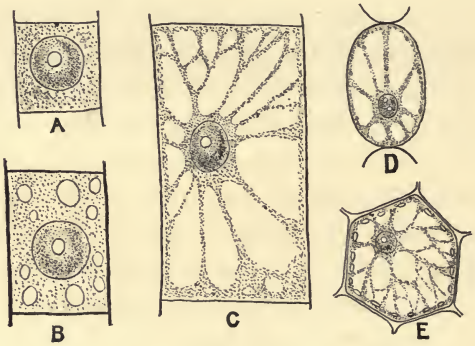


FIG. 3.

CELLS UNDER HIGH POWER.

A, *B*, young cells, *C* an older cell from the developing maize-root.
D, cell from the hair of Tradescantia.
E, parenchymatous cell from the cortex of Ranunculus.

A hair from the stamens of the Spider-Wort (*Tradescantia virginica*) consists of a row of rounded cells united end to end. Under the microscope can be seen the purple cell-sap which occupies the greater part of the cavity of the cell. The protoplasm is more easily visible

than in Spirogyra, because here there are no chlorophyll bodies to obscure the view. There is not only a layer of protoplasm lining the cellulose wall of the cell, but a complicated system traversing the cell-sap and connecting the nucleus with the rest of the protoplasmic cell-body.

The most striking fact visible in the Tradescantia hair is the circulation of protoplasm, which is perhaps the best ocular proof that can be given of the "aliveness" of a plant-cell. The circulation is rendered visible by the granules in the protoplasm which flow steadily along the living ropes of which it consists.

The leaves of the river-weed *Elodea* are useful on account of the visibility of the circulating protoplasm in their cells. In Elodea the chloroplasts differ from those of Spirogyra in being small round bodies instead of spiral ribbons; it is these bodies which make the circulation visible as they glide round the cells carried along in the flowing protoplasm.

The young pith of elder (*Sambucus nigra*) is included as a good general example of the plant-cell, in which the cell-wall, the protoplasm, nucleus and vacuole can all be studied[1]. The cell from the cortex of Ranunculus (fig. 3) illustrates the same points.

[1] As the pith becomes old the protoplasm dies and the cell-contents are replaced by air. The pith is then dry, white and very light.

CHAPTER II.

RESERVÈ MATERIALS—SEEDS OF THE BEAN AND THE GOURD OR PUMPKIN—TUBERS OF THE JERUSALEM ARTICHOKE AND OF THE POTATO—BULB OF THE TULIP.

In the last chapter it was explained how a plant, Yeast or Spirogyra, increases in size by manufacturing new cell-walls and new protoplasm from the food material supplied to it in certain nutrient fluids.

The present chapter is meant to illustrate the important fact that a plant may grow in one part, that is to say that new cells may come into existence and these cells may increase in size, by the rearrangement of food material stored up in another part of the plant. This principle is illustrated in the germinating seeds of the bean and gourd, in the sprouting tubers of the potato and Jerusalem artichoke, and in the bulb of the tulip.

The study of the form of these specimens will also serve as an introduction to some of the simpler parts of the morphology of plants.

A seed, *e.g.* that of the bean, consists of a young plant or

embryo contained in certain envelopes or wrappings. In a dry seed this young plant is alive but it is a dormant, quiescent form of life; in a germinating seed it is on the other hand actively alive, vigorously performing the functions of a living thing, and on the high road to become a full-grown plant. How is it that it is possible to unlock the dormant energies of the bean-seed? Certain changes must be made in the surroundings of the seed. In the first place it must be supplied with water. In the laboratory beans are usually soaked for 12 to 24 hours, during which time they absorb great quantities of water, and increase considerably in weight and size. They change in aspect, become softer and less brittle, while they no longer show the wrinkled seed-coat characteristic of a dry seed.

Secondly, a certain degree of warmth is necessary. A bean seed which has been soaked in water does not grow if kept at a temperature of 0° C. Nor does it grow if the temperature is above 50° C.

A third condition is also necessary, the seed must have free oxygen, it must have access to the atmosphere, or at least to air dissolved in water. If placed in an atmosphere of some indifferent gas such as nitrogen or hydrogen it will not grow.

Respiration is necessary for the life of the seed, and therefore for growth, which is one of the manifestations of life. The respiration of plants is of the same nature as that of animals: it is easy to illustrate this by a simple experiment. A well-stoppered jar is partly filled with germinating seeds; after 24 hours the stopper is cau-

tiously removed and a lighted taper lowered into it is found to be extinguished by the accumulated CO_2.

The point to which I wish to call attention is that given water, free oxygen and a sufficient degree of warmth, the growth of the young plant in the seed will begin although no carbon, nitrogen, phosphorus, sulphur, potassium, etc. have been supplied from outside. Thus a seed will germinate although it has been soaked in distilled water. The fact is that the seed contains a store of food—(the very store in fact which renders seeds valuable as food for animals), and when the young plant grows it does so by the transference of part of this food to the growing regions. The store is known as *reserve material*, and the capability of accumulating reserves and of using them by transference is one of great importance in the lives of plants: it is for this reason that a chapter is devoted to its study.

The seed of the bean is covered by a smooth pale leathery membrane called the *testa* or seed-coat, which presents two special points of interest. At one end of the seed, as shown in fig. 4, is a narrow elongated scar called the *hilum*: it was at this point that the stalk grew by which the bean was originally attached to the inside of the bean-pod; and it was through this stalk that the food was transferred from the mother plant into the developing seed. Near one end of the hilum is a hole known as the *micropyle* which, when the seed was an ovule, played an important part in the process of fertilisation. At present we need only note that it is near the micropyle that the growing root escapes

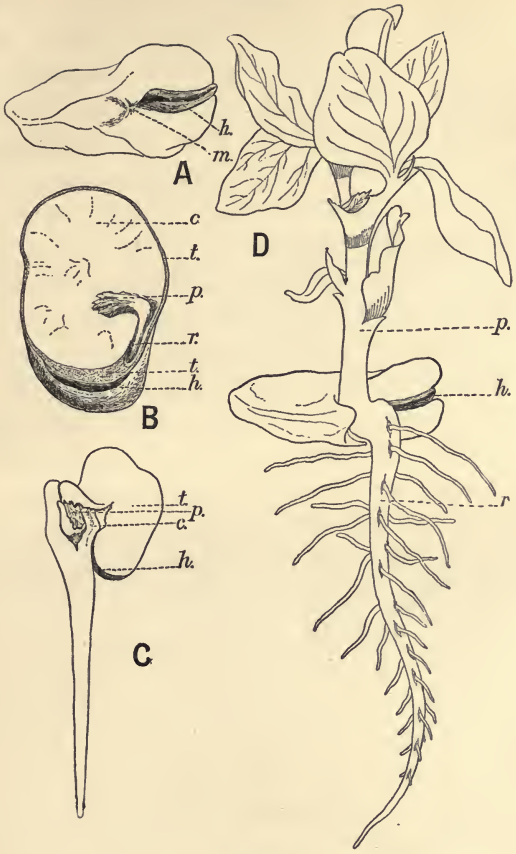


FIG. 4.

A. SEED OF THE BEAN, *Vicia Faba*, in a dry state.

B. THE SEED DIVIDED LONGITUDINALLY.

C. GERMINATING SEED (adapted from Sachs).

D. SEEDLING PLANT.

h, hilum. *m*, micropyle. *t*, testa.

c, cotyledon. *p*, plumule. *r*, radicle.

In fig. *C*, *c* is the stalk of the cotyledon.

from inside the seed-coats; as it does so the testa is seen to give way in the form of a triangular flap, which is shown in fig. 12. But before this stage of germination is examined the structure of the bean-seed must be further described. On splitting it open, the young plant inside is seen. By far the larger part of the plant is made up of two thick fleshy lobes, whose inner faces are flat and lie against one another, and whose outer faces are slightly rounded and impress their form on the seed. These are the two *cotyledons* or first leaves of the young bean-plant. Similar cotyledons are familiar to most people in split peas, which consist of little hemispheres, each being a cotyledon; in the almond too, the oval cotyledons, flat on one side rounded on the other, are familiar enough. The cotyledons of the bean are attached, by stalks at their bases, to a minute stem, one opposite the other. This axis is what will develope into the stem of the bean at one end, and into the root at the other. The end which grows into a stem and which lies between the cotyledons is the *plumule*, the other end which terminates in the primary root is known as the *radicle*. We see in the bean our first example of the general plan of architecture common to a great number of the flowering plants. The plant consists of a short axis or stem-like part, from which spring side growths,—in this case primary leaves or cotyledons. We have here, too, an instance of the division of the plant body into two parts destined to have different functions and correspondingly different structures—namely a *root*-half, and a stem or *shoot*-half. It is an example of a general characteristic of plants that very

early in their development we can draw a transverse line across the embryo which shall divide it into two distinct morphological regions, a point which will be more clearly realised when the embryology of plants is studied.

In the growth of the seedling bean, the first thing that happens is the elongation of the radicle: it is not until the radicle has grown considerably that any striking development of the plumule takes place. This order of growth has a clear biological importance; the young plant must get a hold on the soil before it can raise a structure such as a stem above the ground.

An interesting fact about the plumule is its hook-like form. When a bean is planted beneath the surface of the ground, the part of the plumule which emerges is the curved outline of the hook: it pushes its way through, and makes a path for the delicate tip of the plumule which follows it. If the plumule were straight, the tip would have to make its own way through the soil at the risk of being injured.

The most striking fact about the cotyledons of the bean is that although they are undoubted leaves, they never assume the appearance or functions of ordinary leaves; they do not become green, and they are never expanded in the air and light, nor do they increase in size[1]. Without growing themselves, they give up their accumulated reserve material to the radicle and the plumule.

It is not necessary to consider the nature of all the

[1] The only growth is that of the stalks of the cotyledons, by which the plumule is freed from its position between the cotyledonary lobes and enabled to grow freely upwards: see fig. 4, *C*, *c*.

reserve matters contained in the cotyledons, it will be sufficient to call attention to one class of food—the carbohydrates. If a thin section of the cotyledon is cut, the cells which make up its tissue are found to be crowded with starch grains which give the characteristic blue colour with iodine[1]. The large quantity of starch in the cotyledons may be roughly gauged by a simpler test, namely, by touching the cut surface with iodine solution, when the whole mass becomes dark blue or almost black. Further details about starch are given in the section devoted to the potato.

Gourd or Pumpkin (*Cucurbita*).

The seed of the gourd, shown in Fig. 5, is flattened, oval in outline and marked with a characteristic thickened border. At the square end is the hilum, or scar where the stalk grew, and also the micropyle. The position of this is shown by the outline of the radicle seen through the closely fitting seed-coats, and pointing to a spot close to the hilum. In the gourd, as in the bean, the cavity of the seed is found to be occupied by a young plant—and a plant, moreover, consisting of two large flat cotyledons attached opposite one another to a central axis made up of the plumule and radicle. Another resemblance is that here as in the bean the cotyledons contain reserve materials on which the growing plumule and radicle feed[2]. But in other respects the process of germination is

[1] Either the alcoholic tincture or iodine dissolved in potassium iodide solution.

[2] In the gourd, oil takes the place of the starch in the bean.

strikingly different from that in the bean. The cotyledons do not remain inside the seed-coats, they throw off that

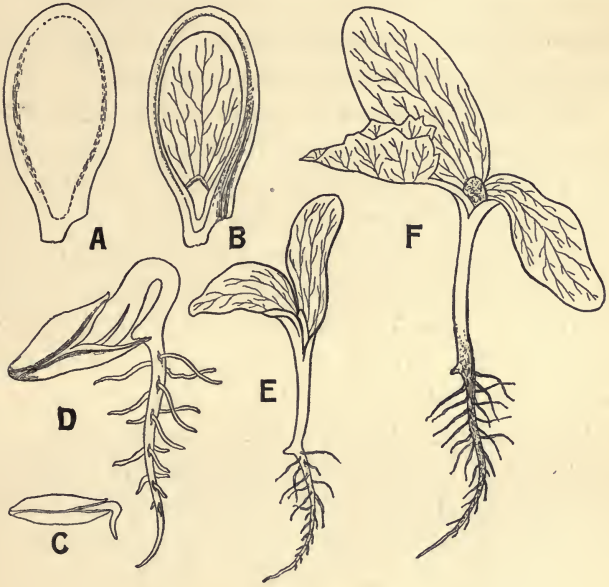


FIG. 5.

GERMINATION OF THE GOURD (*Cucurbita*).

A, the seed.

B, the seed laid open, showing the embryo; one veined cotyledon and the radicle are visible.

C, the radicle has grown out from the micropyle and curved downwards geotropically.

D, the peg or heel has caught on the seed-coat while the growth of the arched hypocotyl has nearly freed the cotyledons.

E, the cotyledons are freed and the hypocotyl has become straight.

F, the first foliage leaf has appeared.

covering, emerge from the soil in which the seed was buried, and begin in fact to lead the life of true leaves.

That is to say, they become green, and in gaining chlorophyll they at once endow the young plant with the power of earning its own living, because they give it the power of gaining carbon from the air to be built up into the store of organic material already existing.

The manner in which the gourd germinates is in some ways unique. The radicle as it emerges from the seed grows downward and fixes itself in the soil[1]. On its lower side a sharp projection or peg grows out as shown in fig. 5. The peg serves to hold down the seed-coat while the cotyledons (with the plumule between them) are extracted. This extraction is effected by the growth of that part of the primary axis of the plant which is just below the cotyledons, and which is known as the *hypocotyl*. A simple proof that the peg is really of value may be got by removing that part of the seed-coat on which the peg should act; when this has been done the cotyledons remain in the seed; although they are finally freed by their own growth bursting the testa.

When the arched hypocotyl has made its way through the soil it straightens itself, and points vertically upwards; the cotyledons increase in size, develope chlorophyll and, instead of remaining face to face, open out and take up a roughly horizontal position, thus exposing their upper surfaces as efficiently as possible to the light. The plumule then begins to increase vigorously and the plant soon grows out of the stage in which it can be called a seedling. The most striking feature in the developing plumule is that it bears leaves having no resemblance

[1] See the account of *Geotropism* in Ch. III.

to the cotyledons; they are not only of different shape and consistence, but are differently arranged on the stem.

Potato (*Solanum tuberosum*).

The accumulation of reserve material is by no means confined to seeds, and it is especially well seen in those underground parts of plants which are known as bulbs and tubers. The potato is a good example of the tuber, and the fact that it contains a store of food intended for the future use of the plant, but diverted for his own use by man (and by the potato-disease fungus) is sufficiently familiar.

FIG. 6.

HORIZONTAL UNDERGROUND STEM, or rhizome of a sedge, sending adventitious roots downwards and leaves upwards.

From Le Maout and Decaisne.

Although the tuber of the potato is formed underground, it is essentially a stem and not a root. It is only one instance of a common state of things, namely, that the underground parts of plants are not necessarily roots. Many plants have creeping underground stems, like the sedge shown in fig. 6. A similar morphological arrangement will meet us in the fern. In the case of the potato the thing is not so evident; perhaps the most striking proof that can be offered to one who has no knowledge of morphology is that under certain conditions tubers are formed on the aerial stem of the plant as in the specimen sketched in fig. 7.

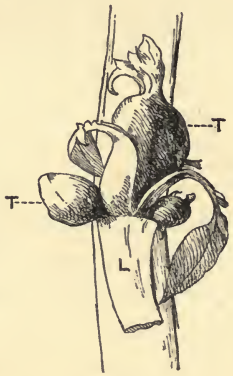


FIG. 7.

FORMATION OF TUBERS ON THE AERIAL STEM OF A POTATO-PLANT.

T, *T*, tubers: *L*, the stalk of the leaf in whose axil *TT* appear.

Moreover fig. 8 suggests that the elongated organs which end in tubers are branches, since they spring from the axis above the cotyledons and therefore *a fortiori* above the line dividing root from shoot.

At present it may be taken for granted that the tuber of the potato is a stem. It is a stem in which growth in

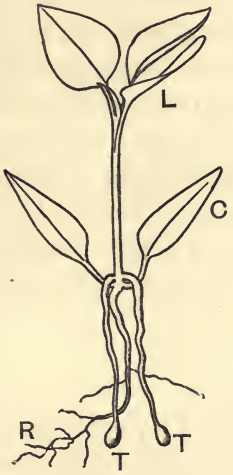


FIG. 8.

SEEDLING POTATO-PLANT BEARING TUBERS.

L, leaves. *C*, cotyledons. *TT*, tubers. *R*, root.

thickness has been excessive, as may be seen by comparing the tuber with the stalk which bore it. The biological meaning of the tuber is illustrated by the use to which gardeners put it in the culture of the plant; instead of sowing the seed of the potato they cut up the tuber into bits, and plant these; they take advantage, in fact, of the part which the tuber is destined to play in the natural course of the plant's life, namely, to provide for the continuance of the species.

It is a bit of everyday knowledge that the gardener cutting up a potato for "seed" takes care that each bit

shall contain an "eye." The eyes of the potato are little crumpled or withered looking nodules sunk in depressions on the surface, which the unwary might pass over as diseased spots, or as due to other casual injury. The bud-like character is apparent on cutting a section (at right angles to the surface of the potato) through the eye; such a section shows a dwarf stem and very small leaves. The scars which occur at the eyes are the remains of rudimentary scale-like leaves, which are plainly visible in the young tuber. The fact that the "eyes" grow in the angles (*axils*) of these leaves is another point demonstrating the stem-like character of the potato. This point is more fully dealt with in Chapter IV.

There is one point which strikes the observer who compares the growth of a potato bud with that of a seed: namely, that in the bean there is a radicle ready to grow into the root-system of the plant, whereas in the potato-eye there is a young stem but no young root. Nevertheless the potato plant, which grows out of the eye, has roots, and the question whence they come has to be answered. They will be found to grow out of the stem of the developing plant. When this occurs the growth is called *adventitious*. A familiar example of adventitious roots is to be found in the ivy, where the roots, by which the plant adheres to and clambers up a wall or tree, grow out of the branches, as shown in fig. 9.

With regard to the nature of the food-stores in the potato we shall only consider the carbohydrate part of the reserve—namely, the starch. The potato is one of the commercial sources of starch, supplying, for example,

that used by washerwomen. In the laboratory it supplies a material for the microscopic study of starch. A section

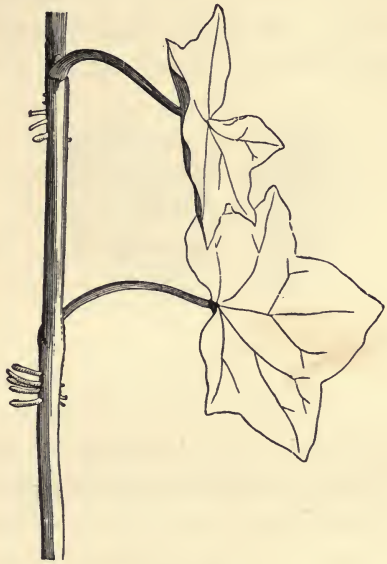


FIG. 9.

YOUNG BRANCH OF IVY,
showing adventitious roots.
From Le Maout and Decaisne.

through the flesh of the potato shows the following things:—on the outside is a layer of cells arranged in a regular manner like bricks one over the other. These form a layer of *cork* serving as a protective layer on the surface; it will not be necessary to consider it in any detail, but it should be noted that it is beneath the corky layer that the starch is found. The main body of the tuber is made up of *parenchyma*, a tissue of simple cells fitting together like bees'

cells in a honeycomb, and rounded or angular in outline. It is in the cavities of these six-sided cells that the starch grains are stored, and in such quantity that the cells are crammed with them. A few grains are shown in fig. 10. A drawing does not indicate the peculiar bright,

FIG. 10.

STARCH GRAINS FROM THE TUBER OF THE POTATO, highly magnified, showing the stratification.

shining appearance of the grains, but it shows their other chief feature, namely, their finely striped appearance. The fine lines indicate what is known as the *stratification* of the grain, that is to say, that it is made up of a set of shells one within the other. The shells are not loose, one from the next, but are rather like the sheets of paper that go to make up cardboard. Stratification is not peculiar to starch, it is an important feature in the structure of cell walls—as will appear in a later chapter, where too we shall have to consider the origin and meaning of the stratification.

I have spoken of the transference of food material from reserve-stores to places where growth is going on and where therefore food is needed. The transference of starch from one part of a plant to another depends on

the power which the plant has of converting starch into sugar. This power depends on the possession by the plant of a ferment called *diastase*.

The action of diastase will not be considered in detail but it is worth noting that the essential features of the process may be studied in any brewery. Barley is made to germinate, its starch changes into sugar and is transferred to the sprout of the grain. Finally this sugar is used by man with the help of another plant—yeast—to make alcohol.

Jerusalem Artichoke (*Helianthus tuberosus*).

The Jerusalem Artichoke supplies an example of a state of things similar to that described in the potato; the tuber is a swollen underground stem stored with reserve-material[1] and bearing buds corresponding to the eyes of the potato. They are relatively larger and more obvious than those of the potato, and the leaves in whose axils they grow are easily seen.

Tulip (*Tulipa gesneriana*).

When the flowering stem of the tulip appears above the ground in the spring, it does so by means of growth carried on by the expenditure of reserve material stored up in the underground bulb; so that from a physiological point of view, the interest of the tulip-bulb is the same as that of the tubers described above. Morphologically however it differs from these; the chief bulk of the bulb is not a solid mass like the potato, but is made up of fleshy scales

[1] The carbohydrate is not starch but *inulin*.

fitting closely over one another. These are morphologically leaves, and it is for this reason that it bears a different name —*bulb*, because its reserve materials are stored not in a thickened stem but in specially modified swollen leaves. Nevertheless its resemblances to a tuber are more important than its differences, for the swollen scaly leaves are necessarily borne on a stem, so that the bulb only differs from the tuber in the predominant development of leaves, which are insignificant in the last named.

It is well to begin by examining a bulb growing in the garden during the summer. In the centre is seen the stalk which, during the spring, bore leaves and flower; it can be seen to be continuous with the main axis of the bulb which bears the scales. It should be noted that these scales are no longer plump and fleshy, but dry and withered; this is because they have yielded their stores to supply material for the development of the flowering stem. Since the bulb is exhausted it is not obvious in what way next year's flowering stalk is to be provided for. In fig. 11 (A) it will be seen that on one side of the flower stalk a new bulb has formed: the leaves on the flowering stem have, during the summer, built up more organic material than the plant needed, and this has been transferred downwards, and has led to the growth (out of a minute bud hidden among the scales) of a new bulb. Next spring this bulb (B, fig. 11) will throw up a leafy and flowering stem, will be in its turn exhausted, and will among its scales give birth to another new bulb. The death of the old bulb going on side by side with the development of a new

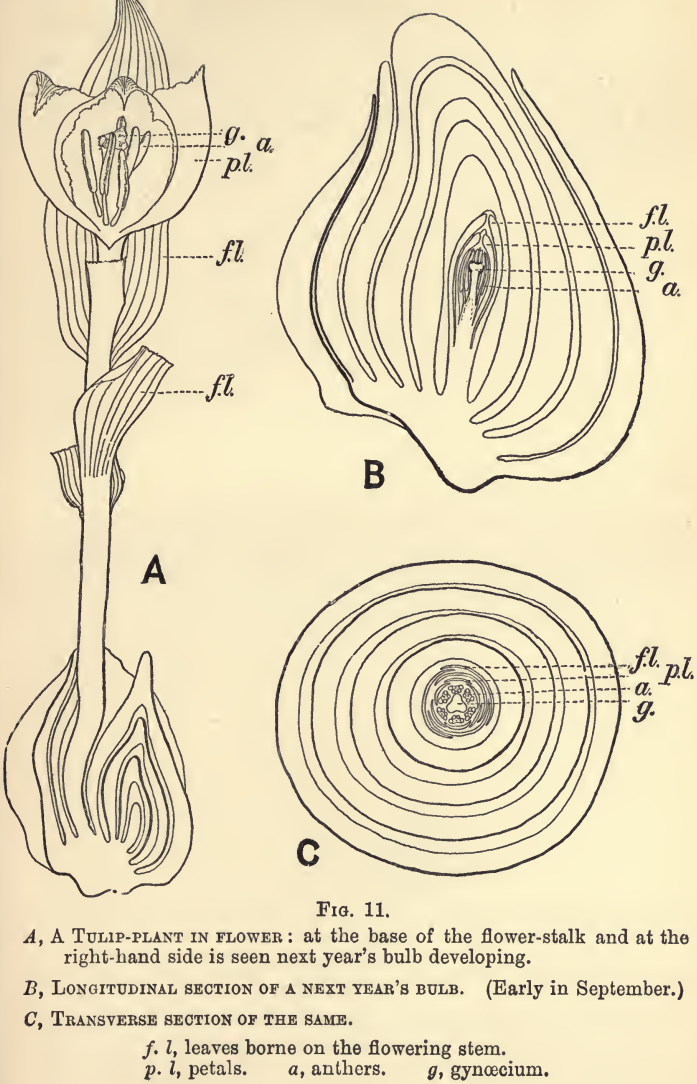


FIG. 11.

A, A TULIP-PLANT IN FLOWER: at the base of the flower-stalk and at the right-hand side is seen next year's bulb developing.

B, LONGITUDINAL SECTION OF A NEXT YEAR'S BULB. (Early in September.)

C, TRANSVERSE SECTION OF THE SAME.

f. l, leaves borne on the flowering stem.
p. l, petals. *a*, anthers. *g*, gynœcium.

one produces, during the summer, a one-sided appearance in the bulb, the flower-stalk is no longer central because the main body of the structure is made up of the new-born bulb, which has grown laterally and deformed the symmetry of the whole.

CHAPTER III.

ROOT—GEOTROPISM—TISSUES—VASCULAR CYLINDER—MERISTEM—ROOT-CAP.

In a bean-seed which has not begun to grow, the radicle lies in the plane of the cotyledons and points towards the micropyle. If a bean is sown (*i.e.* placed in damp soil) with the micropyle downwards and the plane of the cotyledons vertical (fig. 4 c), the radicle will grow straight on in the direction in which it naturally points: but if the bean is allowed to germinate lying on its side with the plane of the cotyledons horizontal, this will not happen, the radicle will bend at right angles to itself until it points vertically downwards, and will then continue to grow in that line as shown in fig. 12. In fact, in whatever

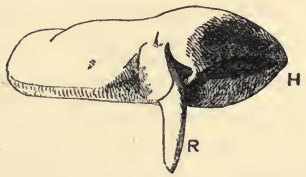


Fig. 12.

Germinating Bean.

The radicle (*R*) has curved geotropically downwards : *H*, the hilum.

position the seed may be placed, the radicle will bend until it reaches the vertical, and will go on growing downwards towards the centre of the earth. This mode of growth is known as *geotropism*, and is but one out of a number of special powers which the plant possesses of directing its growth according to external circumstances. It used to be believed that the radicle attained the vertically downward position in virtue of plasticity, that it bent over by its own weight as a piece of sealing-wax bends if kept in a warm place. This is quite a mistaken view: we now know that the curvature of the root is an active process due to a rearrangement of longitudinal growth. That is to say the curvature results from one longitudinal half of the root growing more quickly than the other half. We further know that this rearrangement of growth is a response to a stimulus quite as certainly as that the movements of animals are brought about by stimulation. It is not of course suggested that a plant has consciousness, nor do we claim consciousness for muscles or nerves. But botanists do claim for plants an irritability or sensitiveness by means of which the plant's movements are directed to suit its environment: they believe that by this sensitiveness the growth of the plant is directed in the same unconscious way that the flight of a moth may be supposed to be directed towards a lamp. I shall return to this point when the upward growth of the stem into the air is discussed, but I think it is worth noting that at the very outset of the life of the plant, in its germinating state, it is endowed with and guided by a very remarkable kind of sensitive-

ness or irritability. This quality of growth which enables a root to grow straight down into the ground is of obvious use to it, for it thus fixes itself most quickly and most effectively in the soil in which it has to play its part in the plant's economy. Before going on to the functions of the root it will be well to consider its structure.

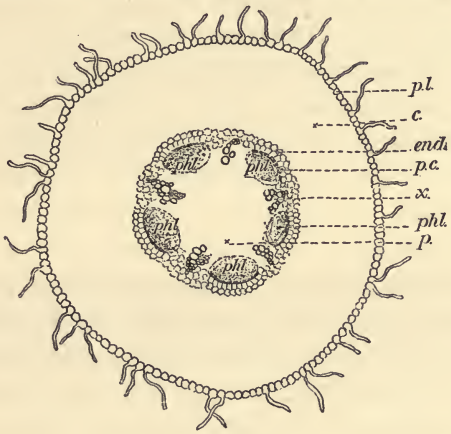


FIG. 13.

TRANSVERSE SECTION OF THE ROOT OF *Vicia Faba* (semi-diagrammatic).

p.l, piliferous layer bearing root hairs.
c, cortex, the cells of which are not shown.
end, endodermis.
p.c, pericycle
x, xylem
phl, phloem
p, pith
} central cylinder, or *stele*; see Preface on the use of this term.

Fig. 13 represents a transverse section of the primary root of a bean not far behind the tip, as seen with a low power of the microscope. In the centre of the section is a circular mass of cells differing in texture and aspect

from the rest, which is known as the *central cylinder*; the region that surrounds it is known as the *cortex*, and the layer of cells which limits the cortex, and at the same time limits the outer surface of the root, is the *piliferous layer*. If the central cylinder is examined a little more closely it will be seen that it presents certain obvious patches imbedded in substance not unlike the cortex in general appearance. These patches are elongated masses or ropes of tissue running longitudinally in the root and known as *vascular* strands. Both the cortex and the substance in which the bundles are imbedded are made up of tissue which like the parenchyma of the potato tuber is built of cells whose length is not strikingly different from their width.

In distinguishing the vascular strands from the rest of the root, histologists make use of the word *tissue*: they speak of vascular tissue and parenchymatous tissue. It is extremely desirable, but by no means easy, to seize and define the meaning of this important term. When a mass of objects is presented to us, our impulse is to classify them; and the finer elements in vegetable and animal structure are classified into tissues. But not every classification that can be made is a classification into tissues. The conception is to some extent arbitrary, and has to be learned rather than evolved from general principles. It is possible, however, to give certain characteristics common to tissues.

One such characteristic is that the cells or elements making up a tissue obey a common law of growth. Thus the vascular strands in the root, although made

up of numerous cells, have a sort of individuality: each cell grows, and behaves generally, as if it were coordinated with all the other cells of the strand. The cells making up the vascular strand behave like the soldiers of a regiment, and give to the strand the same sort of unity that comes from the combined and ordered behaviour of drilled men.

On the other hand many tissues are chiefly characterised by being made up of a mass of similar cells. Thus the tissue in which the vascular strands are imbedded is a mass of simple rounded or angular cells, to which the term parenchyma is applied, as in the case of the similar tissue in the potato tuber; here the criterion of unity of growth is not so obvious.

Lastly some tissues are more especially tissues by birthright: that is to say they are classified together because they are found to be developed in a similar way from an embryonic cell or group of cells. Examples of tissues in which this character is strong will be met with later on.

I am now concerned to point out the difficulties which meet the beginner in trying to seize the idea of a tissue. On the whole it is best to let the conception grow gradually: if he works out the histology of plants in the laboratory, and reads books in which the terminology is not incorrect, he will gain the idea in the best and easiest manner.

Root-cap.

If a bean-root is held up against the light, it will be seen that it ends in a conical point, *C*, fig. 14, and that inside the root a curved outline *M* can be dimly seen. The

main body of the root ends at *M*, and the part that gives the conical form seems to be made of less dense material.

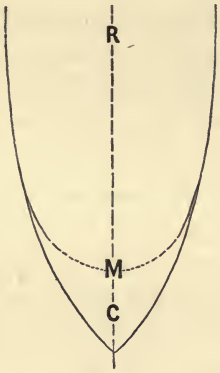


FIG. 14.

A ROOT-CAP DIAGRAMMATICALLY REPRESENTED.

R, root. *M*, meristematic region. *C*, root-cap.

These appearances, somewhat obscurely seen with the naked eye, correspond to actual and important facts. The cap-like part *C* is a structure highly characteristic of roots, a region of the root of great interest and importance, known by the name of *root-cap*. The surface of the root-cap is slimy because the most outward of its constituent cells are constantly becoming disorganised, and in the natural life of the bean they are, as they die, rubbed off against the resisting soil penetrated by the root. In spite of this wear and tear the root-cap is not entirely worn away: this should suggest that, like the skin on the human hand, it is renewed underneath as it is worn away outside. This is the case, and it is at the

region *M* about the centre of the limiting line, that new cells are being manufactured to replace the ones that are lost. Not only is the region *M* the manufactory of root-cap cells, but it is also the manufactory of cells which go to form part of the main body of the root. Thus if we were to examine a longitudinal section of a root, and if we carried our observation along the centre line *RMC* in fig. 14, we should discover this remarkable state of things:—well-grown differentiated cells at *R*, and again at *C* differentiated root-cap cells, and between them at *M* a small quantity of *meristematic* tissue, minute, delicate, simple undiffer-

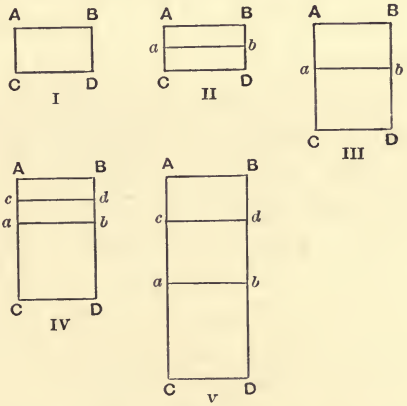


FIG. 15.

DIAGRAM ILLUSTRATING MERISTEMATIC (OR MERISMATIC) TISSUE.

I. a meristematic cell *ABCD*. II. a cross-wall *ab* has appeared.

III. *AabB* has grown and again equals *ABCD* in size, while *aCDb* has also grown.

IV. *AabB* has been divided by a cross-wall *cd*.

V. *AcdB* has again grown, it equals *ABCD* in size and is ready again to divide. Meanwhile *cabd* and *aCDb* have increased in size considerably.

entiated cells, which will in time give rise in their turn to root on one side and root-cap on the other. This tissue makes up what is known as the *growing point* of the root and of the cap. Several things have to be noticed about meristematic tissue: one is what may be called the quality of perpetual youth. Let *ABCD*, fig. 15, be a meristematic cell, and let it be divided into two compartments by the transverse cell-wall *ab*. The lower half will give up its embryonic character and will begin to make part of the permanent plant-body. But the other half *AabB* retains the embryonic merismatic character, and when it has again grown to its original size it again divides by a line *cd*. The process may be repeated indefinitely, so that we get a row of cells of which the topmost retains the capacity of continued division and all the rest are on the way to become permanent tissue.

I began by speaking of *M* (fig. 14) as a manufactory of cells, and this is a convenient expression, but it must always be understood that in such a manufactory, cell originates from cell, and that the process of manufacture is cell division of such a sort that half the divided cell remains capable of keeping the work going.

In thinking over the growing point of a root we are liable to fall into a false conception; we think of cells being manufactured one on the top of the other like bricks which make up a wall, and we may imagine, when the new layers of cells have been made and laid on the older layers, that they have done their work, that they have increased the size of the plant by their diameter, just

as bricks put on raise a wall by a single course only. But this would be quite wrong; each cell that has been created by cell-division at the growing point undergoes great increase in size before it becomes a permanent member of the root.

The root of the bean is not so easily understood or so instructive as that of the maize, and the drawing (fig. 16) which illustrates root-structure is therefore taken from that plant.

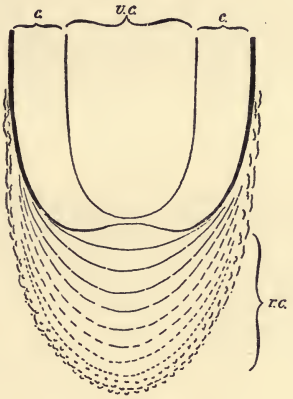


FIG. 16.

DIAGRAM ILLUSTRATING THE STRUCTURE OF THE ROOT-TIP IN LONGITUDINAL SECTION.

c, cortex. *v.c*, central cylinder. *r.c*, root-cap.

The points to notice are (1) the central cylinder *cc* seen in longitudinal section, ending a dome-like mass of meristem. Then (2) the cortex which thins away to a layer of meristem only one cell thick, which keeps forming new cortex cells. Then (3) the sharply marked root-cap *rc* whose new cells are made by another layer of meristem.

The central cylinder is surrounded by an envelope or cylindrical sheath, one cell in thickness, which in section

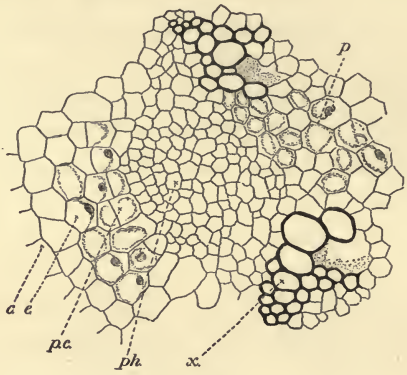


FIG. 17.

PART OF FIG. 13, TRANSVERSE SECTION THROUGH THE ROOT OF *Vicia Faba*, under a high power.

c, cortex. *p*, pith. *x*, xylem. *ph*, phloem.
e, endodermis; in this specimen the "spindles" on the radial walls were only apparent opposite the phloems.
p. c, pericycle, which in the bean is of two layers opposite the phloems.

shows as a ring of cells. This is known as the *bundle-sheath* or *endodermis*. It may be recognized because the radial walls, those which separate cell from cell, have a peculiar appearance, due to their being delicately undulated, and producing the effect of a dot or spindle. In the root of the bean however this character endodermis is not easily seen.

Within the endodermis comes another sheath of cells called the *pericycle*: this is usually a one layered sheath, but in the bean it is in places several cells in thickness.

The endodermis is the innermost layer of the cortex: the pericycle the most external layer of the central cylinder.

Within the bundle-sheath 8 or 10 patches of tissue, 4 or 5 being of one kind, 4 or 5 of another, alternate with each other as shown in fig. 13, where *phl* and *x* alternate as the eye travels round the circumference of the axial cylinder. The patches marked *x* are known as *xylem*, the alternate ones *phl* are called *phloem*. *Xylem* and *phloem* are the constituents which, in vascular plants, *i.e.* plants with vessels, make up the vascular tissues. At present we are only concerned with the xylem; it is made up of vessels, a vessel being a pipe or tube built up of cells placed end to end, the constituent cells of a vessel being excessively long in proportion to their diameter.

The striking feature about them is that they have no cell-contents; the protoplasm which they originally contained, and which regulated their behaviour whilst they were developing, dies and disappears. Moreover the cross walls, which are the end walls of the constituent cells, become disorganised, and disappear, either in part or completely, so that the vessels finally come to be elongated tubes without protoplasmic contents. The walls of the vessels undergo moreover a peculiar change, they are no longer ordinary cellulose; they have been *lignified*,—changed in such a way that they no longer react chemically like cellulose.

The root is thus seen to be characterised by the presence of elongated tubes running along its whole length, which might suggest the transference of fluid

through the root; and this in fact is their function, for it is through these pipe-like vessels that the water collected by the roots in the soil is transmitted to the parts of the plant above ground. The absorption of water by the root requires among other things that the root shall present a large surface to the soil. It is only by the extraordinary multiplication of surface that the plant is able to perform what seems an impossibility: thus, if a plant is kept for some time without water it is found, just before it finally withers, to be obtaining water from soil apparently as dry as dust. It is not usually realised to what a depth and width roots extend; in a field of winter wheat the roots have been found reaching to seven feet beneath the surface, and in a single oat-plant it was calculated that the length of the root including its branches was 150 feet[1].

This manner in which roots branch has therefore some importance.

The roots which grow out from the primary root are called *secondary*, these in their turn give off *tertiary* roots. The first thing that strikes the observer is that it is only on the older part of the root that secondary roots are seen. Near the base (fig. 4), *i.e.* on the oldest part of the root, are seen the longest, *i.e.* the oldest secondary roots; and in the region below they are shorter, while they are not to be seen in the apical region. The figure also shows what is characteristic of the secondary roots, namely, that they are arranged in longitudinal rows, the roots in each row being accurately one above the other. This arrangement,

[1] Johnson's 'How Crops Grow,' Dyer and Church's edit. 1869, p. 233.

which gives a curiously formal, symmetrical look to a branching root, depends on the fact that the secondary roots spring from opposite the xylems, and since the strands of xylem run straight down the primary roots, it follows that the bases of the secondary roots run also in vertical lines. The primary roots, as explained before, have a quality of growth which enables them to grow straight down; the secondary roots have a similar, but not an identical, quality of growth, in consequence of which they grow, roughly speaking, horizontally, or rather somewhat obliquely. In this way they parcel out space between them, the four secondary roots emerging at any given level, run out north, south, east, and west. It is clear that there will be unoccupied soil between the secondary roots, especially when they have grown to some length; this space is taken up by the tertiary roots, and these are not guided by any directive quality of growth in relation to gravity but run out upwards, downwards, right and left, thus making the most of the vacant places.

One other characteristic of the growth of secondary (and tertiary) roots must be described. In the fig. 4, at the base of each secondary root, in the row facing the observer, can be seen a vertical slit or cleft, through which the root passes. This is explained by the mode of origin of these organs, namely, that they arise in the pericycle. That is to say, one or more cells in the pericycle of the primary root begins to divide and form a mass of new cells which constitute a very young secondary root. In this stage, shown in fig. 18, it is obviously invisible from the outside, since it is covered in by cortex. As it grows

in length it pierces the tissues and burrowing through the cortex breaks out at the surface, leaving in the cleft surrounding its base, evidence of its internal manner of origination.

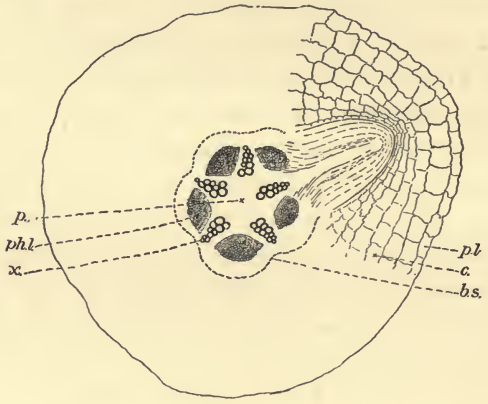


FIG. 18.

TRANSVERSE SECTION OF THE PRIMARY ROOT OF THE BEAN, showing a secondary root developing.

p. l, piliferous layer. *c*, cortex. *b. s*, endodermis.
x, xylem. *phl*, phloem. *p*, pith.

The surface of root in contact with the soil is still further increased by the growth of what are known as *root-hairs*. These can be especially well seen in seedlings of the mustard, cabbage, or one of the cereals. A seedling mustard which has germinated in damp air gives the appearance shown in fig. 19. The base of the root, where it joins the young stem, bears a dense frill of delicate colourless hairs; nearer to the tip of the root they are younger and therefore shorter, and at the tip of the root they are not found. A transverse section (fig. 13) would

show that each hair is an external cell elongated by growth at right angles to the surface of the root. When

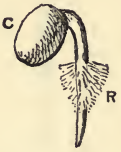


FIG. 19.
MUSTARD SEEDLING,
showing the cotyledons (*C*), and the root covered in its older part by root-hairs (*R*).

it is understood that each of the innumerable rootlets of a well-grown plant bears root-hairs, it will be realised how enormously the surface of the root is multiplied. The nature of the contact between the plant and the soil is extremely close; if a plant is removed from the soil and examined under the microscope it can be seen how the root-hairs press against, even to some extent wrap round and adhere to, minute particles. The adhesion of the root-hairs to the soil can be simply demonstrated by pulling a seedling up from loose soil, when it presents the appearance shown in fig. 20. The apical region of the root comes up clean and bare, while the basal region is shaggy with its coat of earthy particles. In older plants a further fact may be demonstrated in the same way. In these the basal, as well as the apical part of the root is bare, because the root-hairs are short-lived organs, and where they are dead the root does not retain its envelope of soil.

I have spoken of the root absorbing water, but it must

be remembered that the water so absorbed is the vehicle by which the plant receives two-thirds of its food material,

FIG. 20.

A SEEDLING WHEAT WITH SOIL ADHERING TO THE ROOTS. (After Sachs.)

for it is in this way that nitrogen in the form of nitrates, sulphur in the form of sulphates, phosphorus as phosphates, calcium, potassium, magnesium and iron reach it. To this part of the subject I shall return.

CHAPTER IV.

THE STEM OF THE SUNFLOWER. MORPHOLOGY AND HISTOLOGY.

THE present chapter deals with the structure of stems, and for the sake of convenience this part of the plant-body is studied in the sunflower instead of in the bean or pumpkin. The sunflower, *Helianthus annuus*, is a near relative of the Jerusalem artichoke, *H. tuberosus*, and what is here said applies, speaking generally, to both.

The germination of the sunflower is of the same general type as that of the pumpkin; the embryo has a pair of large fleshy cotyledons loaded with reserve matter, which like those of the pumpkin expand above ground and function as leaves, that is to say, they become green with chlorophyll and they assimilate. Between the cotyledons is the minute plumule; it bears a number of undeveloped leaves crowded together, and surrounding a growing point. It is in fact a bud which will lengthen out into a tall stem on which fully developed leaves will take the place of the semi-developed ones now clothing it. The growing point at the extremity of the plumule differs in detail from that of the root; it has for instance

nothing corresponding to a root-cap, but it has the essential characteristics of places where new cells are manufactured by division; it in fact possesses the embryonic character, or quality of continual youth.

In a growing plant in which the stem has begun the process of elongation several important points may be noted:—

In the first place the leaves are markedly different in form and texture from the cotyledons. But the most striking point to be noted is one which, by its extreme familiarity, tends to be forgotten,—namely, that the stem is divided into alternate regions, (1) which have, and (2) which have not, lateral outgrowths. The places where the leaves spring out are known as *nodes* (fig. 21), and the alternating leafless regions as *internodes*. Thus, like the body of a worm or an insect, the plant-body is segmented into a number of definite regions from which the lateral appendages spring. The distinction into nodes and internodes comes out clearly in the growth of a bud, where a certain division of labour is apparent: the nodes, which bear the leaves, do not increase in length; while the internodes, free from leaves, increase greatly in length. The unfolding of a bud is therefore the simultaneous growth of the internodes, and of the leaves at the nodes.

There is an important difference between the manner of development of the lateral outgrowths of stems and roots. The secondary roots have their origin deep down in the tissues of the primary root. In the stem the outgrowths arise on the surface. The growing point of the stem will be found to end in a blunt, rounded end, and below this to

present a series of rounded excrescences, those nearest the point being the youngest and smallest, and those further

FIG. 21.

STEM OF PIMPERNEL (*Anagallis*).

To illustrate the alternation of nodes and internodes.
(From Le Maout and Decaisne.)

away being older and approaching more and more the form of young leaves.

If the stem is split longitudinally in such a way

that the section also bisects a leaf and leaf-stalk longitudinally, it will be seen that in the acute angle between the leaf-stalk and the stem, *i.e.* just above the insertion of the leaf, is a bud, similar in character to the small bud which lay between the cotyledons and gave origin to the main stem. This bud which, if it developes, will grow out into a branch bearing leaves in its turn, is called *axillary*, from its position in the *axil*, or armpit-like angle above the leaf (see fig. 21), and it is a fact of broad general significance that normal branches always spring from the axil of a leaf. This general law is useful in understanding the structure of certain plants: of this the potato- and the artichoke-tuber have already supplied instances, for the eyes or buds grow in the axils of leaves whose traces are visible in the markings on the surface of the tubers. It makes it possible also to understand such a plant as the Butcher's Broom (*Ruscus aculeatus*). Here the observer sees the stem beset with flat green outgrowths, which he naturally takes for leaves, until a closer examination shows him that each outgrowth springs from the axil of a scale-like rudimentary leaf. This observation points to what is the truth, namely, that the outgrowths are flattened branches functioning as leaves, and taking the place physiologically of the useless but true leaves in whose axils they grow.

Although it is not always possible to tell a leaf from a branch by its appearance, there are nevertheless some characters by which the two can be distinguished. In the first place, leaves differ from branches in the limited character of their growth. A leaf soon ceases to

have any embryonic tissue, in other words, all the cells which compose the leaf soon take on a permanent character. Compare for instance the leaf of an oak and the branch that developes from the bud in its axil; the leaf increases until it attains a length of 2 inches or so, and then it grows no more, but the branch grows year after year and continues to bear, in the buds which cover it, innumerable growing points.

Another point is of importance; the flowers, which are the reproductive parts of a plant, are borne on branches, whereas the leaves do not bear flowers. This may be illustrated again by the Butcher's Broom, whose flowers grow on the flattened leaf-like branches above described. The position in which the flower is borne has also a wider morphological importance. It is one of the characters that distinguish the whole of the root-system from that of the stem. At first sight it seems absurd to appeal to such a character to mark off root from stem, since a typical stem and a typical root are so different in appearance. But in the potato an underground rootlike stem has been met with, and in the fern another instance will occur. Roots, on the other hand, are by no means always underground: the aerial roots of the ivy have been described, and many such cases occur; we must therefore look for more fundamental distinctions. It has been seen that a stem, the potato-tuber, may be devoid of chlorophyll, but it might have been hoped, when a part of a plant is found to be green, that then at least we should know it not to be a root. But certain tropical orchids have flat green aerial roots which actually

do the work of leaves in assimilating carbon. The criterion of the absence or presence of chlorophyll fails therefore, and we are driven to see that the absence or presence of flowers may be of value.

The obvious external characters of the sunflower stem may be summarised before going on to its microscopic characters. The points to be noted are that it is a vertical structure divided into nodes and internodes, the nodes bearing opposite[1] leaves, or in the case of the lowermost node opposite leafy cotyledons; it terminates in a growing point and bears buds (which are potential branches) in the axils of its leaves.

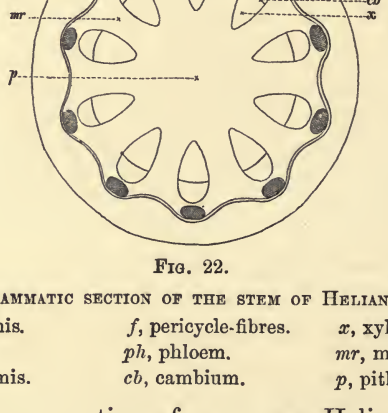


FIG. 22.

DIAGRAMMATIC SECTION OF THE STEM OF HELIANTHUS.

ep, epidermis.	*f*, pericycle-fibres.	*x*, xylem.
c, cortex.	*ph*, phloem.	*mr*, medullary ray.
e, endodermis.	*cb*, cambium.	*p*, pith.

A transverse section of a young Helianthus stem presents certain resemblances to the section of a root, while

[1] In *Helianthus tuberosus* the leaves are in sets of three, and there is some irregularity in their arrangement in the sunflower.

it differs from it strikingly in detail. The resemblances are, however, of a more fundamental nature than the points of difference. The chief part of the section is taken up by a cylinder, the *central cylinder*, which corresponds to the region bearing the same name in the root, with which it is indeed continuous. In the diagram, fig. 22, the cylinder is marked out by the double line *e*. Outside the central cylinder is a region known as the cortex: the cortex is covered by a single layer of cells *ep*, forming a special tissue known as the *epidermis*. This tissue is of great importance both morphologically and from the point of view of function, and will be considered in detail in a later chapter. The most internal layer of the cortex is the line *e*, fig. 22, already referred to, which bears a name identical with the corresponding layer in the root, *viz. endodermis*. In the stem it generally pursues a wavy course, as in the figure, and may be easily recognized by the presence of starch grains in its cells. In the centre of the central cylinder is a large mass of pith, *p*: in the growing condition the pith is juicy, soft and greenish in colour; but after a time, long before the whole plant dies, the pith changes its character: its cells die, that is to say, the protoplasm inside them dies; they no longer contain cell-sap but become filled with air. It is now no longer a green and sappy, but a dry, white, spongy and very light substance, like the pith of a woody elder branch, or like the pith used in the laboratory in cutting sections.

Surrounding the pith is a broken ring, made of a series of dots; this ring feels hard and woody to the

razor, and if the stem is split longitudinally it will be obvious that each dot corresponds to a rope or strand of fibrous tissue running down the stem. Each of these dots is a vascular bundle, and is seen in fig. 22 to be made up of a mass of vascular tissue (*ph, x*) and of a patch of fibres (*f*). These fibres[1] were, until recently, called *bast* fibres; they are now usually described as *pericycle*-fibres because they originate in the region known as the *pericycle*, which forms the external limit of the central cylinder.

It should be noted that between the vascular bundles, avenues of parenchyma run towards the cortex: these radiating paths by which, except for the pericycle, pith and cortex are joined, are known as medullary rays, and will be seen later on to be of great importance.

Each vascular bundle consists of three kinds of tissue, as seen in figs. 22, 23, 24.

I. *Xylem*, nearer the pith.

II. *Phloem*, nearer the cortex.

III. *Cambium*, between the two.

The arrangement differs strikingly from that of the root where free strips of xylem alternated with free strips of phloem; here each vascular strand contains both xylem and phloem. (See Preface on the word *stele*.)

[1] There seems to me no substantial inaccuracy in using the term *bast* for the pericycle fibres as well as for the hard elements of the phloem. The word becomes purely descriptive and does not assert a common origin of the tissues to which it is applied.

The word xylem indicates that it is the woody part of the bundle, and it will appear later that the wood of trees, in the ordinary sense of the word, is in fact chiefly

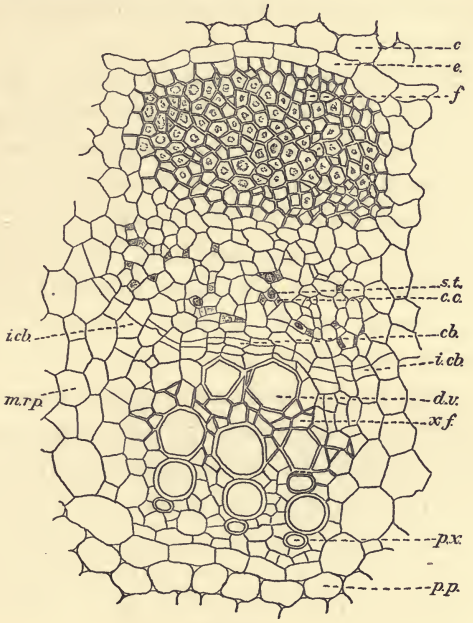


FIG. 23.

TRANSVERSE SECTION THROUGH THE STEM OF *Helianthus tuberosus*, THE JERUSALEM ARTICHOKE.

c, cortex.
e, endodermis.
f, pericycle-fibres.
s. t, sieve tube.
c. c, companion cells.
cb, cambium.
i. cb, interfascicular cambium.
m. r. p, medullary ray.
d. v, dotted or pitted vessel.
x. f, xylem fibre.
p. x, spiral vessel.
p. p, pith.

made up of the xylem of a great number of vascular bundles.

The word phloem on the other hand points to a likeness to the bark of trees, and here again it will appear that the term is well used, since the phloem part of the bundle in the sunflower is a tissue allied to the external tissues of trees.

The most essential character common to the xylem and phloem is that which gives to both the quality of vascular tissue, namely, the fact that they consist *largely* of tube-like elements or vessels built up of long cells placed end to end. In the xylem as well as in the phloem there are also non-vascular tissues made up of cells not fitted together into tubes. So that xylem and phloem are made up of:—xylem vessels and xylem cells, phloem vessels and phloem cells.

The points of difference are perhaps more striking than the points of resemblance. The xylem vessels (like the vessels in the root which were briefly examined) are hollow tubes empty of protoplasm, whereas the vessels of the phloem contain protoplasm. The xylem vessels have but few partitions, the cross-walls of the constituent cells having mostly disappeared. The cross-walls in the phloem-vessels have not disappeared, and moreover present a peculiarity which is especially characteristic, and which has given rise to the name *sieve-tubes* by which these vessels are known. The cross-walls of the sieve-tubes are perforated by numerous holes (like a sieve), and through these holes one constituent cell communicates with the next in the row. Not that the cavities communicate, for the minute holes in the *sieve-plates* (as the perforated cross-walls are called) are filled

by delicate ropes of protoplasm, by which means there is continuity of the living element from cell to cell throughout the sieve-tube.

Another point of difference between the xylem vessels and the sieve-tubes (phloem vessels) is the character of their walls: the walls of the xylem vessels are no longer simple cellulose, but have suffered a change known as lignification. They are firmer and more resisting than the soft sieve-tube walls, but the difference between the two is not merely one of texture, they are chemically different. The xylem vessels no longer give the reaction of cellulose with Schulze's solution, which colours them yellow, while the sieve-tube walls still give the purple colour characteristic of cellulose.

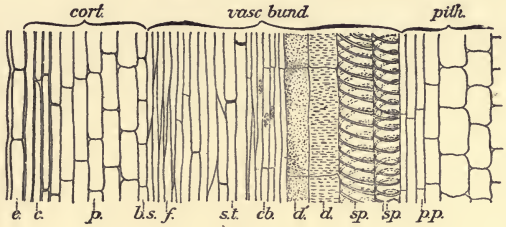


FIG. 24.

LONGITUDINAL SECTION THROUGH THE STEM OF *Helianthus tuberosus*, THE JERUSALEM ARTICHOKE.

cort, cortex.
e, epidermis.
p, parenchyma of cortex.
f, pericycle fibres.
cb, cambium.
sp, spiral vessels.
vasc. bund, vascular bundle.
c, collenchyma.
b. s, endodermis.
s. t, sieve tube.
d, *d*, dotted or pitted vessels.
p. p, parenchyma of pith.

When a longitudinal section of the xylem is examined with a high power (fig. 24) it will appear that the vessels are of various kinds. Near the inner margin they are very narrow in diameter and are marked by a spiral line, further towards the circumference they are wider and the walls are covered with dots instead of being spirally marked. These two kinds of vessels are known as *spiral* and *dotted vessels*. To understand the meaning of this it is necessary to consider the way in which cell walls are thickened. When a transverse section of a cell wall is examined under a high power of the microscope it can be seen to be delicately striped by numerous parallel lines, so that it seems to be made up of concentric layers or shells as described above in starch-grains. This appearance is known as *stratification* and has been the subject of much

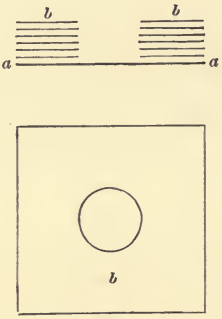


FIG. 25.

MODEL REPRESENTING THE STRUCTURE OF A PITTED CELL-WALL:

b represents a square sheet of paper pierced by a circular hole; in the upper figure a number of sheets like *b* are shown in section pasted one over the other, the lowest being pasted to an unperforated sheet *a*.

research and of no little disputing among botanists. It is now generally believed that the lines of stratification represent successive films of cellulose added by the protoplasm to the cell wall. A single sheet of paper, which is thickened by pasting on to it other sheets, may serve as a model of the thickening cell wall, and will in transverse section give the same stratified appearance as an actual cell wall. Fig. 25 represents a model of a more complex case. The original sheet of paper (*a*) on which the successive sheets are pasted is unperforated, while each of the sheets (*b*) to be fastened over it is pierced by a circular hole. The resulting thick sheet of paper will when seen in transverse section have the appearance shown in the figure.

If the perforated sheets had been pasted on to both sides of the whole sheet the model would have represented a dotted or pitted cell wall, in which a similar appearance is produced in roughly speaking the same way. Fig. 26

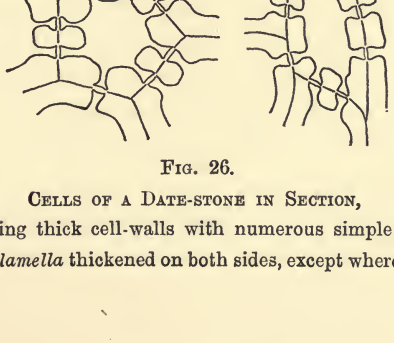


FIG. 26.

CELLS OF A DATE-STONE IN SECTION,

showing thick cell-walls with numerous simple pits.

m.l, the *middle lamella* thickened on both sides, except where the pits occur.

represents what is known as a *pitted* cell wall; the depressions are the *pits*, and the thin layer, which separates pit from pit, is the *pit-membrane*.

The dots seen on the walls of the large xylem vessels are pits of a slightly more complicated kind than that shown in fig. 26. The spiral lines and rings which distinguish the narrow vessels at the central side of the bundle are the result of still more complicated thickening.

In the xylem the non-vascular elements are the cells forming the parenchyma of the xylem, and the *xylem-fibres* (fig. 23 *x.f*), elongated, tapering, thick-walled cells. In the phloem attention must also be called to certain non-vascular elements,—minute elongated cells, called *companion cells*, whose chief interest from our present point of view is that they give a characteristic aspect to phloem in transverse section and help us to learn to recognize this tissue. The phloem also contains some simple cellular elements making up the *phloem parenchyma*, which is of no special importance.

Fig. 24 shows in longitudinal section the *pericycle fibres* to which reference has already been made. They are narrow elongated elements with very small cavities and thick, lignified walls, lying directly internal to the endodermis. They form a tough resisting tissue possessing in fact, to some extent, the quality that gives a commercial value to the fibres of the flax, hemp and other plants.

There remain to be considered the cambium and the cortex.

Cambium.

The cambium is a *meristematic* tissue lying between the xylem and phloem. It is a cell-manufactory, where by cell division new elements are added to the neighbouring tissues, viz. xylem and phloem. Thus the new cells which arise in the cambium go to increase the xylem and phloem something in the same way as the meristems at the growing point of the root yield cells for the increment of root and root-cap.

The cambium will be studied in more detail in the next chapter. In the cambium of the sunflower there is one point of great importance as being introductory to the study of the oak. It will be seen in fig. 23 that in the spaces between the bundles, that is to say, across the primary medullary rays, a tissue is forming precisely like the cambium which lies *in* the bundle. It finally extends across the medullary ray and joins the cambium of one bundle to that of the next. Thus instead of there being mere strips of cambium running longitudinally down the stem between the xylem and phloem, there comes to be a cylindrical sheath of cambium made up by the coalescence of the cambium of the vascular bundles with the *interfascicular cambium* that arises between the vascular bundles.

The origin of the interfascicular cambium is physiologically of interest; it is due to a kind of rejuvenescence, for the cells which lie between the bundles are mature, and in beginning to divide once more and becoming cambium, they regain as it were the quality of youth. The architectural importance of interfascicular cambium will be considered in the chapter on the oak. It will here

suffice to know that the cells to which it gives origin in Helianthus go to form fibrous and vascular elements which partly fill up the spaces between the original bundles.

Cortex.

The points to be noticed in the cortex are not many. Under the single layer of epidermis are several layers of cells of which the walls are thickened in such a way as to give a certain clumsy look to the outline, and which have moreover a peculiar gloss or sheen.

These two characters, the glistening texture and the peculiar thickening of the walls, are common to tissue of this kind, which is known as *collenchyma.*

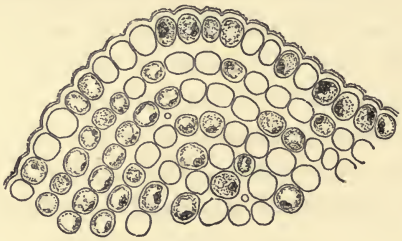


FIG. 27.

TRANSVERSE SECTION THROUGH A RIDGE ON THE STEM OF CLEMATIS.

Beneath the epidermis the section shows a mass of collenchyma remarkable for the thick walls separating adjacent cells: the protoplasmic contents have fallen out of many of the cells.

Lastly, the cortex contains running through it a number of ducts or tubes known, from the nature of their contents, as *resin ducts.* In transverse section a duct appears as a space surrounded by a rosette of 5 or 6 cells. The physiology of resin ducts is obscure and need not be discussed.

CHAPTER V.

THE OAK—GENERAL STRUCTURE OF A TREE-TRUNK—HISTOLOGY OF XYLEM.

THE seed of the oak (*Quercus sessilis* and *pedunculata*) contains an embryo with two large fleshy cotyledons; these do not serve as assimilating organs, but supply food to the plumule, which springs up above ground and developes into the stem of the young tree.

In its younger stages the plumule bears hardly any obvious resemblance to the woody trunk of the older tree. It is herbaceous rather than tree-like; its structure is that of an annual plant, such for instance as the sunflower. It has a considerable mass of central pith, a ring of scattered vascular bundles, and a cortex covered by epidermis. Compare this structure with that of an oak trunk: here the epidermis has disappeared, the pith is visible only as a relatively small speck in the centre of the section, while the concentrically marked wood, which makes up the bulk of the trunk, does not much resemble the scattered bundles of the seedling. The problem is to understand how the structure of the tree has developed from the herbaceous structure of the seedling.

The development depends upon the activity of the cambium, which in the seedling oak has the same form as

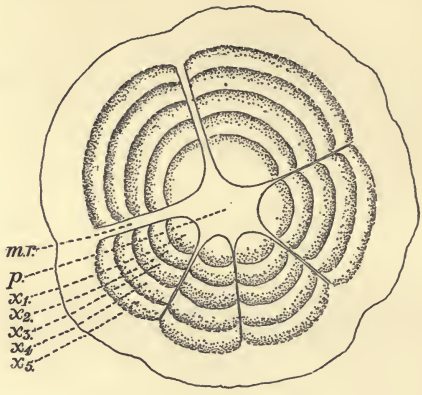


FIG. 28.

TRANSVERSE SECTION OF A FIVE-YEAR-OLD OAK-BRANCH in which the isolated bundles are replaced by concentric shells of wood.

p, pith. $m.r$, primary medullary ray.

x_1 to x_5, shells of xylem formed during successive years.

The secondary medullary rays are not shown.

in the sunflower, namely, a cylindrical shell looking like a ring in transverse section.

As in the sunflower so here the cambium manufactures cells on its inner side which become xylem, and cells on its periphery which become phloem. It therefore follows that the cambium manufactures a cylindrical shell of xylem on one side and a cylindrical shell of phloem on the other.

As already mentioned the pith can be seen as a small speck (fig. 29) in the centre of the section of an oak-tree,

and this tissue helps us to make out the general structure of a tree-trunk: for though it looks small in comparison with the diameter of the stem, it is the same pith that looked big in the section of the plumule. The pith has not grown, and the mass of new tissue has therefore nothing to do with it. It ought to be possible to discover another fixed point by which to guide ourselves. The cambium ring should still be recognizable, since it remains perpetually young, and therefore unchanged. Between the bark and the wood there is found a layer of cells (noticeable in the spring-time for its sliminess) which proves under the microscope to be the cambium, the direct descendant of the cambium ring of the seedling and like it composed of delicate meristematic tissue.

With the help of these two fixed points, the pith and the cambium, the tissues of the oak branch may be classi-

FIG. 29.

TRANSVERSE SECTION OF AN OAK-TRUNK, 25 years old.

From Le Maout and Decaisne.

fied. What lies between the pith and the cambium, and is known as wood, must be xylem; all outside the cambium must be phloem and cortex. Again, there were in the

seedling, rays of tissue passing between the bundles; these should still exist, and they can in fact be clearly seen (together with other medullary rays of later origin) running radially outwards, as shown in fig. 29. One other point can be made out in the same way; the wood of the stem or branch increases in size every year by the conversion of a number of cambium cells into woody tissue, and since the cambium is in the form of a hollow cylinder, giving a ring in section, it is clear that a ring of wood must be added every year; these are the concentric markings seen on the section of the stump, from which the age of a felled tree can be calculated. These circles, known as *annual rings*, are shown in the section of an oak stem, in figs. 28 and 29.

With a simple lens or a low power it can be seen why the annual rings are so clearly marked out. The concentric circles visible to the naked eye are shown in fig. 30 to consist of lines of large vessels. If the eye travels from the centre to the circumference of the section, it will be seen that it is the central margin of each annual increment that is marked by a line of large vessels. In each annual layer the vessels become smaller and less frequent at the peripheral margin, till at the beginning of the next year's growth the row of large vessels again suddenly appears. But even in places where the vessels are absent the ring can be detected by the close texture of the non-vascular elements formed in autumn. It should be noted that the mere fact of the tree growing in summer and resting in winter does not necessarily produce visible alternations in structure. A tree grows in length

as well as breadth every year, but a branch split lengthwise does not show transverse horizontal marks in the wood

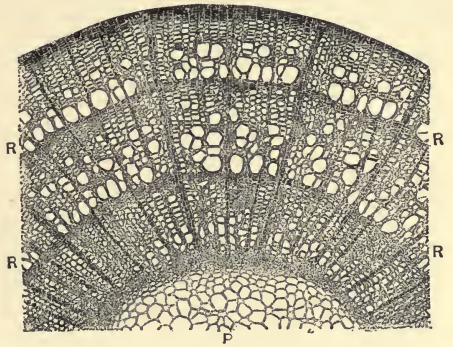


FIG. 30.

TRANSVERSE SECTION OF THE WOOD OF THE LIME-TREE, to show the annual rings.

P, pith.

R, *R*, lines of large vessels in the spring wood of the annual rings. After Van Tieghem.

where the year's growth begins, the tissues of one year are continuous with those of the next. Or to take a simpler example: if a builder were to build for a week and rest for a week and so on, it would not be possible afterwards to point to the places where pauses had occurred. But if he always began with a course of big bricks and ended with a course of small ones, the resting places would be revealed.

Much discussion has been held as to the physiological meaning of the annual rings: it is clear why the tree grows in summer when it has leaves with which to assimilate, and light and heat with which it can work its

assimilating organs, but it is not clear why the vessels formed in the spring should be bigger than the later formed ones. The most probable explanation is that of Strasburger—namely, that the large vessels are needed for the rise of sap in the trunk, which occurs in the spring.

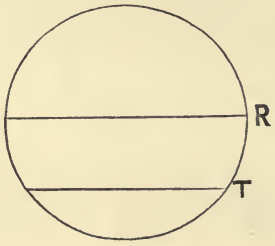


FIG. 31.

DIAGRAM ILLUSTRATING TWO TYPES OF LONGITUDINAL SECTION.

The line *R* would divide the cylinder by a *radial* section, *T* by a *tangential* section.

Certain points can be made out by means of longitudinal sections examined with a simple lens or with a low power of the microscope. Longitudinal sections are of two kinds. If a branch is divided longitudinally by an incision which passes through the centre, the surface exposed is a *radial* longitudinal section; this is shown in fig. 31, where *R* represents the line along which the branch (here seen in section) is divided.

But the incision may be longitudinal, that is to say, parallel to the axis of the branch, and yet may not pass through the centre, it is then called a *tangential* section, as shown by the line *T* in fig. 31.

If an oak branch of three or four years old is split down the middle, and if the radial section thus exposed is

examined with a simple lens, two things will be apparent; the surface is longitudinally striped owing to the general longitudinal character of the tissue, but there are also very evident transverse markings. These must correspond to radiating lines in the transverse section, and they are in fact the medullary rays. In a section examined under a higher power their structure comes out as shown in fig. 32.

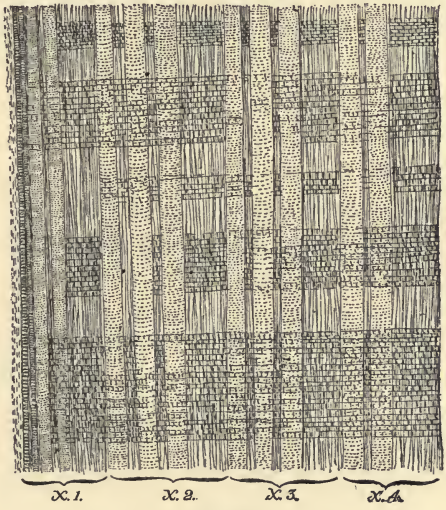


FIG. 32.

LONGITUDINAL RADIAL SECTION OF THE WOOD OF THE OAK.

x_1 to x_4 represent the xylems of successive years, the dotted vessels appear at the left of the brackets x_2 to x_4; at the left of x_1 are the spiral vessels of the protoxylem.

The medullary rays run like walls transversely across the section.

Each medullary ray is like a wall of brick-shaped cells, the bricks being supposed to stand on their edges; their

walls are thickened, lignified and pitted, and enclose living protoplasm and a good deal of starch. The bigger medullary rays are several cells in width, while the smaller ones are but one cell wide, but this of course does not show in longitudinal section. In either case the ray is a plate of cellular tissue with its edges pointing upwards and downwards. The medullary rays are of various depths (*i.e.* in the direction of the axis of the branch), the primary rays being the deepest. The exact form of the ray can best be seen in a tangential section. In fig. 31 the line *T* represents such a section, and it is clear that, since the medullary rays run like radii from the circumference towards the centre, they must be cut by *T*. Thus a tangential section of the branch gives approximately transverse sections of the medullary rays. The rays represented in fig. 33 are one cell in thickness

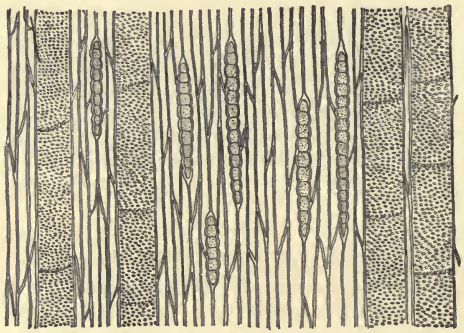


FIG. 33.

LONGITUDINAL TANGENTIAL SECTION OF THE WOOD OF THE OAK, showing dotted vessels and tracheids among which are the medullary rays.

and from 6 to 15 or more cells in depth; it will also be seen that the top and bottom edges of the rays end in ridge-like cells, triangular in outline, which give to the rays the form of double-edged blades.

Cambium.

To understand the part played by the cambium it is necessary to examine it under a high power. The beginner will not find it easy to prepare sections of the requisite amount of fineness owing to the delicate nature of the tissue. But although he will not be able to see as much as is shown in the figure (fig. 34) taken from Strasburger, yet he ought to be able to make out some of the chief points. The most characteristic feature about the cambium is the radial arrangement of its cells. The arrangement is so regular that it enables us to sketch

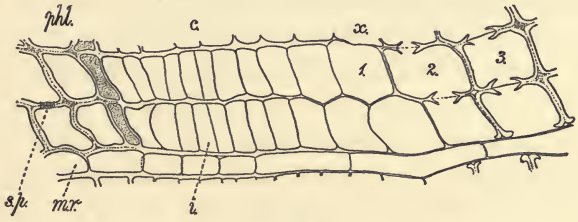


FIG. 34.

TRANSVERSE SECTION OF THE STEM OF THE SCOTCH FIR (*Pinus sylvestris*).

phl, phloem; *s.p*, sieve-plate; *m.r*, medullary ray; *c*, cambium; the letter *c* is opposite to the initial cell *i*; the youngest or latest formed cell wall forms the right hand wall of the cell *i*; it may be recognized by ending flush against the radial walls.

In the xylem, 1, 2, 3 represent stages in the development of the bordered pits which characterize the tracheids of the pine.

After Strasburger.

the cambium in the most diagrammatic way without being seriously inaccurate.

Fig. 34 gives, much magnified, a small portion of the cambium of a pine-tree. Towards the middle of the ladder-like radial row is a delicate transverse wall which abuts sharply on the radial walls. This is the last cell wall that has been formed, and gives evidence that this is the actual region of cell manufactory or as it is called the *initial layer* of the cambium. The cells on either side of the initial layer are on their way to becoming permanent tissue, and the change in form which accompanies increasing age can be clearly made out. In the pine-tree the xylem is made up of vessel-like elements known as *tracheids*, and at 3 such tracheids are seen cut across in transverse section; then comes a younger tracheid (2) with thinner walls, and lastly a tracheid (1) with thin walls and without the "bordered" pits[1] characteristic of the fully developed elements. Between such elements as (3) and the cells of the initial layer there is a gradation of cells, intermediate in age between the adult and the initial stage, and also intermediate in appearance. There is a similar gradation from the initial layer towards the phloem, but it is not so clearly visible.

In longitudinal (radial) sections the character mentioned above is shown in a similar way. Namely, that in the radial direction cells of equal length are arranged one behind the other like books in a shelf.

A function of the cambium, which is sometimes

[1] See the account of bordered pits in the next section.

overlooked by beginners, is the production of medullary rays. Certain of the cambial cells, instead of developing into xylem or phloem elements, turn into medullary ray cells; in this way the rays which already exist are continued outwards as the trunk thickens, and at the same time new rays make their appearance in each annual ring. This will be understood by a reference to fig. 35; it will be seen that only the original *primary* rays run from pith to bark, while the rest (*secondary rays*) arise in one of the annual rings, whence they are continued radially outwards by the addition of the medullary ray cells manufactured year by year by the cambium.

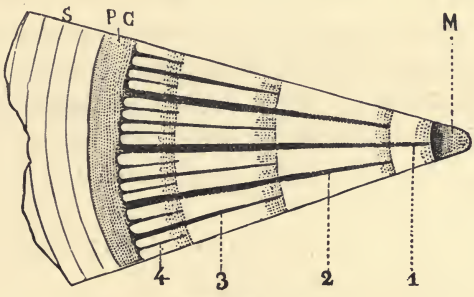


FIG. 35.

PART OF A TRANSVERSE SECTION THROUGH A FOUR-YEAR-OLD BRANCH OF THE CORK OAK.

(1), a primary medullary ray running from the pith (*M*) to the bark.
(2), (3) and (4), secondary rays formed in successive years.
PC, phloem and cortex. (*The medullary rays should be continued into the phloem.*) *S*, cork.
From Le Maout and Decaisne.

There remains to be considered the structure of the wood as seen under a high power of the microscope.

Transverse Section.

The pith cells contain living protoplasm and also starch at certain times of the year, their walls are thickened and pitted. The pith presents an irregular outline because the primary vascular bundles project into it all round in the form of blunt wedges. At the ends of these wedges, or apparently embedded in the pith, are the first formed vessels, of narrow diameter and lined with a spiral thickening. Spiral vessels occur nowhere else in the wood[1]. The most obvious elements in the transverse section are xylem vessels, looking like holes of various sizes punched in the section, the largest being in tangential lines in the parts of the xylem formed in the spring. The medullary rays are seen running in radial lines across the section, some of them one cell in thickness, others consisting of many cells, and containing in certain seasons large quantities of starch. The way in which the rays bend round the larger vessels should be noted; this distortion is due to the great increase in size of those cambium cells which turn into vessels, pushing the rays out of their true radial course.

Besides the vessels there are a large number of thick-walled woody elements which make up the rest of the xylem. These are not easy to classify as seen in transverse section, the wood-parenchyma may however be often distinguished by the starch grains which it contains.

[1] It must be remembered that the spiral character is not perceptible in transverse sections.

Longitudinal (Radial) Section.

The large xylem vessels are again the most striking feature. They appear in longitudinal section as empty spaces with here and there a remnant of an oblique transverse wall. The markings on the walls can be seen well where fragments of membrane come into the section as shown in fig. 36.

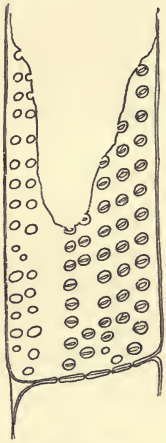


FIG. 36.

PART OF A DOTTED XYLEM-VESSEL FROM THE OAK.

These markings, from which the vessels take the names of "dotted" or "pitted," are like so many screw-heads, a disc traversed by a transverse line or elongated mark which represents the groove for the screw-driver. The structure of these pits, which are known as *bordered pits*, can be explained by an imaginary model. Imagine a pair of watch-glasses each pieced by a narrow slit, and imagine them united face to face with a delicate circular piece of

paper between them, and then fixed into a hole cut in a thick piece of card. The outline of the screw-head is the outline of the united watch-glasses where they are let into the card: the groove in the screw-head is the oblique cleft which leads into the space between the glasses. The structure will be understood from the bordered pits shown in section in the walls of the tracheid (3) in figure 34. A bordered pit is in fact a thin place in the wall which allows water to pass laterally from surrounding tissues into the cavity of the vessel; the function of the protective "border" (the watch-glasses) need not be discussed.

The remaining elements of the xylem are wood-cells, wood-fibres and tracheids. The cells of the wood parenchyma, as seen in longitudinal section, or when isolated by maceration, are not unlike the medullary ray, seen in tangential section. That is to say, they consist of what was originally a single cambium cell divided into chambers by horizontal walls. The wood parenchyma retains vitality in its constituent cells, which like the medullary rays are loaded with starch grains, especially in the winter.

The *tracheids* (*tr*, fig. 37) and *wood-fibres* (*f*, fig. 37) resemble the vessels and differ from wood parenchyma and medullary rays in having no living protoplasmic contents. The tracheids are in fact closely allied in character and in function to vessels; if in a line of tracheids the transverse walls were to disappear such a line would be a small vessel. Like the vessels too, they serve for water transport. In accordance with this relationship we find that the pits (which are organs of

water transport) in the tracheids are like those of the vessels, namely, bordered.

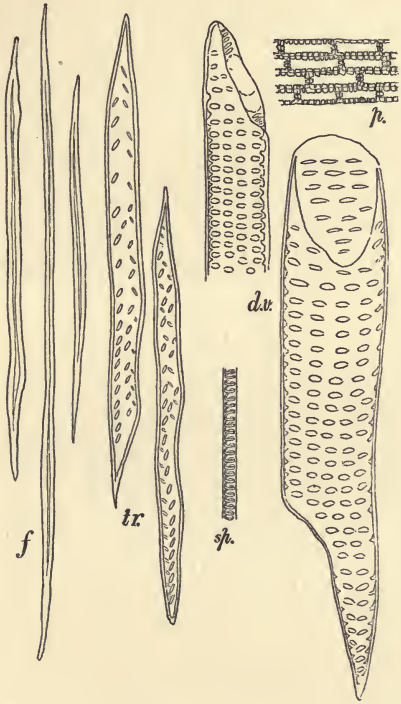


FIG. 37.

MACERATED OAK-WOOD.

f, fibres. *tr*, tracheids. *sp*, spiral vessel.
d.v, dotted vessel. *p*, medullary ray.

The wood-fibres, as shown in fig. 37, are thick walled elongated elements with narrow cavities.

CHAPTER VI.

THE OAK (CONTINUED)—BARK—GROWTH OF TREES.

THE bark in the everyday meaning of the word is that part of the stem external to the cambium. I propose to use the term in this sense in spite of the fact that in English botanical books it is applied only to the tissues external to the *cork-cambium.*

The bark increases in thickness in the manner described in the case of wood, namely, by cambium cells, as they develope, assuming the form and nature of phloem. And just as the shells of wood formed by the cambial cylinder are known as secondary xylem, so here the products of cambial activity towards the periphery of the stem are known as secondary phloem. But the growth of the bark is more complex than that of the wood for more than one reason.

In the first place it is complicated by the existence of the primary cortex. In the young oak stem as in the sunflower the cortex is the region outside the vascular

cylinder, and since the cambium-ring is formed in the vascular cylinder, the cortex is obviously outside the cambium, and therefore all secondary tissue formed by the cambium towards the outside must at first be covered by the primary cortex.

Secondly, the growth of the wood has an influence on the bark. If the bark were to cease to grow while the cambium continued to make new layers of wood, it is obvious that the bark would be too small for the branch and would burst by pressure from inside. Although this is an imaginary state of things, it is worthy of note, because in spite of the fact that the bark *does* grow, it is nevertheless stretched by the growing wood, and this helps to produce a distortion and compression of the elements which are characteristic of the bark.

Thirdly, the structure of the bark depends partly on the growth of certain tissues which have no connection with the cambium, but which originate in a meristematic layer in the primary cortex. It will be convenient to describe this tissue—the *corky* layer—before dealing with the secondary phloem.

In a young oak twig the epidermis is seen as a limiting membrane, a pavement of a single layer of cells. The outer wall of each cell *c*, fig. 38 (p. 83), has (as is usual in epidermic cells) a special character. It is not only thicker than the other walls but strikingly different in its chemical nature; it is no longer pure cellulose, but is *cuticularised.*

The layer forming the cuticularised outer walls of the epidermic cells is known as *cuticle.* It resembles

lignified tissue in giving a yellow instead of a blue colour with Schulze's reagent. It is however especially remarkable for its resisting power. If a section is placed in strong sulphuric acid, ordinary cellulose walls are destroyed, but the cuticle is not destroyed. Plants in a state of nature are not subject to baths of sulphuric acid, but this test shows at any rate a resisting power which gives the cuticle value as an external armour-plating to the epidermis.

In older branches the epidermis disappears, and its place is taken by several layers of *cork-cells*, whose walls have a similar but not identical resisting quality: the walls of cork-cells are not said to be cuticularised, but to be *suberised*.

The young oak twig is green, because the cortical cells contain chlorophyll, but it begins to turn brown in its first year, the brown colour being due to the growth of a layer of cork covering up the green cortex like a veil. This film-like appearance would suggest that the cork arises on the surface of the cortex. It does not however arise in the most superficial cells, *i.e.* in the epidermis, but in the cells immediately under the epidermis. In this layer a remarkable change takes place precisely like that rejuvenescence which gives origin to the inter-fascicular cambium. The sub-epidermal cells begin to divide by tangential walls, and thus a cambium-like ring is formed immediately inside the epidermis (*ph* in fig. 38).

This meristematic layer has, like the vascular cambium, a double activity: it adds to the cortex on its central side and manufactures cork on its external epidermal side. It

is often described as *cork-cambium*, but more technically as *phellogen*. In the same phraseology cork is sometimes

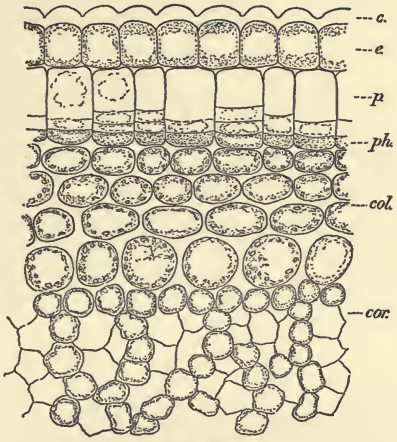


FIG. 38.

TRANSVERSE SECTION THROUGH ONE-YEAR-OLD BEECH-BRANCH, showing the development of cork.

c, cuticle. *e*, epidermis. *p*, developing cork-layer.
ph, phellogen. *col*, collenchymatous cells of the cortex.
cor, cortex. (The phelloderm is not yet formed.)

called *phellem*, and the cortical tissue arising from the phellogen is called *phelloderm*. The three layers together form the *periderm*[1]. Thus the bark of the oak comes to be made up of three chief parts; the original cortex to which on the inside is added secondary phloem arising from the cambium ring, and on the outside the periderm arising from the phellogen.

The epidermis is stretched and cracked by the cork growing underneath it, and ultimately dies and falls away in flakes.

[1] Some authors use *periderm* to mean *cork* only.

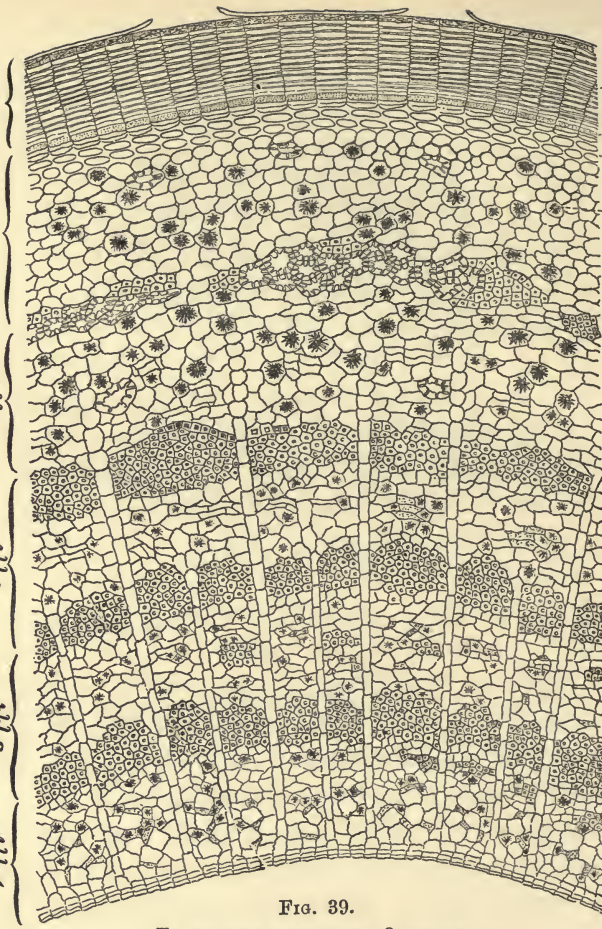


FIG. 39.

TRANSVERSE SECTION OF OAK-BARK.

ck, cork. *phel*, phellogen. *col*, collenchyma of the phelloderm.
cr, crystals. *pc*, pericycle fibres. *cb*, cambium.
p, periderm. (N.B. the bracket *p* should extend more to the right so as to include the phelloderm, *col.*) *c*, cortex.
phl_1 to phl_4, the phloems of four years, the youngest being next the cambium; the outer part of each phloem consists of a layer of bast-fibre *f*; thick-walled pitted sclerenchyma cells are to be seen near *p*: medullary rays run outwards from the cambium.

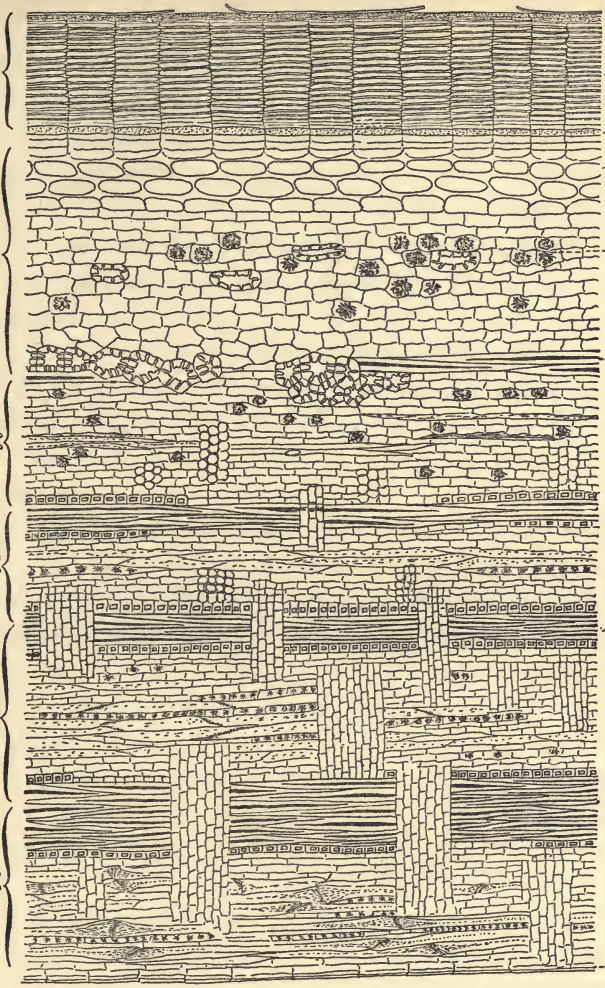


Fig. 40.

Radial longitudinal section of Oak-bark.

Lettering as in fig. 39.

Cubical crystals in vertical rows border the groups of bast-fibre *f*; in phl_4, sieve-tubes are to be seen; medullary rays run across like walls.

The cork-cells being formed by successive division of the phellogen cells acquire the same regular pattern-like arrangement that has been described for the cambium. It is shown in figs. 39, 40, where the cork is seen in transverse and longitudinal section.

The suberisation of the walls of the cork-cells is not the only change that occurs; an equally striking feature is the disappearance of the protoplasmic contents: so that cork, like pith, comes to be a mass of air-containing cells. The fact that the cell walls are extremely impervious to water, added to the fact that the cells contain air, gives the floating power of cork. The impermeability to water also gives the quality which allows the periderm of the Cork Oak to be made into "corks" for bottles.

The phelloderm need not be described in detail: it consists of collenchyma in whose cells chlorophyll-bodies are found.

As the oak-tree becomes older there is a more complex formation of cork, which leads to the rough scaly look observable on the trunk. Into this formation I shall not enter.

Secondary Phloem.

A transverse section of the bark of a 4 or 5 year branch of the oak shows, under a simple lens or low power of the microscope, a stratified appearance. The concentric lines which produce this appearance are due to the same general cause which accounts for the annual rings in the xylem, namely, that the products of cambial activity

are not always the same. In the case of the xylem, the cambium in the spring develops large vessels, while in the autumn smaller elements are produced It is a corresponding series of changes that gives rise to the alternate layers of tissue in the secondary phloem. These layers in the bark are distinguished by a physical character, namely, hardness, and are described as hard and soft phloem.

Fig. 39 represents a transverse section of oak bark highly magnified. At the upper end of the drawing (which represents the outer side of the section) is the cork *ck*, and phellogen *phel*; at the lower edge of the drawing (inner side of the section) are seen the medullary rays running in radial lines. The layers of hard phloem run concentrically at right angles to the medullary rays, separated from each other by concentric layers of soft phloem. Outside the region of alternate hard and soft phloem, and inside the periderm, is the original cortex, the limits of which are not clearly distinguishable in transverse section. In the longitudinal section (fig. 40) the cells of the soft phloem are seen to differ in size and shape from those of the cortex. The cells, which together with sieve-tubes are the essential elements of the soft phloem, are rich in *tannin*, a fact which is familiar from a practical point of view in the use made of oak bark by tanners. The structure of the hard phloem will be understood from fig. 40; it consists of elongated pointed fibres with thick walls and very minute cavities. The layers of phloem fibres are bordered, as may be seen in longitudinal section, by rows of cells, each

containing a crystal of calcium oxalate. The same salt occurs scattered in the soft phloem, but here the crystals are more complex and have a star-like radiate form, as shown in fig. 40.

The hard phloem is what gives the tough resisting character to the bark of trees, and what in the lime tree yields the strong rope-like material known as *bast*.

In oak bark there is another hard resisting tissue shown in figs. 39, 40. The tissue is made up of rounded cells with small cavities and thick lignified walls of great hardness, belonging to the type known as *sclerenchymatous*. The sclerenchyma of the oak is easily recognised by the numerous deep narrow simple pits which traverse the cell walls.

Physiology.

It is not at first obvious why plants should have developed into such huge structures as many trees are. Why should there be Sequoias in America and gum trees in Australia towering two or three hundred feet into the air? This question is asked from an evolutionary point of view, and simply means:—What advantages, connected with the tree-like habit of growth, have, by means of natural selection, guided the evolution of plants in this particular direction? The answer to such questions must be highly speculative; we can never answer them dogmatically. All that can be done is to point out certain undoubted advantages which a plant, in taking on the arboreal habit, gains in the struggle for life. The chief gain is no doubt that a plant, in overtopping

its fellows, gains access to the light, and in shading lower trees tends to starve a possible rival, and thus better its own chance of keeping possession of the light. At the same time in keeping back the aerial growth of its rivals it starves their roots and thus keeps its own roots free from undue competition. Many facts go to prove that this struggle for light is an important feature in the environment of plants. From this point of view it is possible to understand the advantage of the climbing habit in a plant, for it is thus enabled to reach the light by a small expense of actual stem-production: it succeeds by adaptation, instead of by the patient construction of a column-like trunk of massive strength. The same thing is true of *epiphytes*, *i.e.* plants which perch and root on others, such as the innumerable orchids, ferns, Bromelias &c. of tropical forests, which do not necessarily exhibit great extension of growth, but possess adaptations for securing themselves and for obtaining food in their aerial position.

Granted that trees grow up into the air in a competitive search for light, how are they guided, and how enabled to carry on the search? The fact that plants grow straight up, even when forced to germinate in the dark, proves that there exists a directive tendency, in which light plays no part. And when it is found that all over the world the trees grow vertically, it is impossible to help suspecting that the force of gravity, which all over the world acts in the direction of the earth's radius, is the guiding influence.

This is the fact; just as the root of a bean grows vertically down, so the plumule grows vertically up. Both

are forms of geotropism, the root being positively, the stem negatively, geotropic. A seedling bean placed on its side gives evident proof of different kinds of sensitiveness or irritability in its root and shoot, for under the influence of one and the same force, viz. gravity, the root grows towards, the stem away from, the centre of the earth. The force of gravity is a stimulus to which different parts of the plant react in different manners. Gravity is as it were a sign-post by which the plant is enabled to direct its growth in the most profitable manner. The most striking proof that gravity thus plays the part of stimulus, is supplied by the famous experiment of Andrew Knight published in 1806. With the help of his gardener he fitted up a small water-wheel which, being driven by the stream in his garden, rotated rapidly and exposed beans germinating on the circumference to strong centrifugal force. If a flexible or ductile object is fixed to a rotating wheel, it will bend until the free end points radially outwards: in the same way when a bucket of water is whirled violently round by a rope tied to the handle, the water remains in the bucket even when it is upside down, instead of flowing out in obedience to gravity, as it would if the bucket were still. These well-known results make one see that centrifugal force replaces gravitation, and that it affects the object whirled round like an imitation gravity acting in the direction of the radius. Therefore if a stationary bean tends to grow in the line of gravity, a bean whirled round on a water-wheel must grow in the line of the imitation gravity, that is in the line of the radius of the wheel.

This is what Knight found: the stems of the young plants grew towards, the roots grew away from, the centre of the wheel.

Geotropism is not only valuable in enabling a plant to take the shortest line in its upward growth, but it is also important in another way, it plays the part of the plummet to the builder. If a tree had no power of vertical growth it might grow upwards in an oblique direction, and would therefore fall by its own weight.

The question how stability is gained in plants, how they come to be strong enough to stand upright, is of considerable interest. In the first place it should be noted that the herbaceous plant, such as a seedling sunflower, has a stability of a different order from that which enables the oak to rear itself into the air. It is well known that a delicate seedling plant withers if exposed to the sun on a hot, dry day: it loses its stability and droops towards the ground, but, if its roots are supplied with water, it will recover when the damp air of evening checks the evaporation from the leaves. A woody stem, such as that of an oak sapling, is not so affected, it does not collapse when dried.

The reason of this difference may be discovered by experiments. Any juicy, actively growing leaf-stalk or flower-stem will serve as material. A stem of this sort cut from the parent-plant and allowed to lie on the table in the dry air of a room soon loses its stiffness and becomes flaccid. Or we may place it in a 5 per cent. solution of common salt, which robs it of its water by osmosis, just as dry air robs it by evaporation. After it

has become flaccid in salt-solution it can be rendered stiff by replacing it in water.

Or it may be made to collapse and become flaccid by immersion in water at 60° C. But in this case the flaccidity is permanent, because the tissues are killed. When the cells were alive they were tensely filled with cell-sap, which escapes as soon as the protoplasmic lining of the cells is killed by heat. The flaccidity of the dead tissue depends on a loss of fluid from the cells, and this is likewise the cause of the similar though temporary loss of stiffness produced by dry air or immersion in salt-solution.

To understand the problem more fully it is best to take the case of a single isolated cell capable of standing up and supporting its own weight. The cell is stiff just as an air-cushion, tensely filled with air, is stiff. The air-cushion is filled by blowing air into it with a pair of bellows. The cell is filled by osmosis, which depends (i) on the fact that the cell-sap is denser than water, (ii) on the physical properties of the protoplasmic lining.

When the fluid surrounding the cell is denser than the cell-sap, the osmotic flow is from the cell to the fluid; when the reverse is the case, the flow is in the opposite direction, and the cell gains, instead of losing, fluid. Again, when the physical properties of the protoplasm are changed by death, the cell-sap escapes just as the air escapes from a ruptured air-cushion.

When a cell is tensely filled with fluid by osmosis it is called *turgid*, and *turgidity* is the cause of the stiffness of not merely the isolated cell, but also of masses of cells in

which every cell is turgid. Thus the flower-stem and leaf-stalk used in the experiments on withering are stable and rigid, because of the turgidity of the cells which make up the central mass of pith. A woody stem is rigid not from turgidity, but because of the rigidity of its lignified cell-walls.

CHAPTER VII.

THE LEAF—TRANSPIRATION—LEAF-FALL.

It will appear later that the parts of the flower (the petals, stamens, &c.) have the morphological rank of leaves. If these are omitted from consideration, leaves may be classified into (i) *foliage-leaves*, (ii) *scale-leaves*. The first are the ordinary leaves familiar to everyone; the other kind of leaf is smaller, dry and hard in texture, colourless or dingy in tint, devoid of chlorophyll, and protective, not assimilative, in function. Scale-leaves of this sort have already been met with in the potato, the surface of which is marked by the remains of the scales, in

Fig. 41.

Horse-chestnut branch, bearing a terminal and two axillary buds.

whose axils the eyes grow. Scale-leaves again are what make the outer covering of the buds of trees, they are familiar in the horse-chestnut from their sticky outer surface (see fig. 41). In the spring they are seen unfolding and finally falling off to allow the growth of the young branch, *i.e.* the bud, shut up within them. The markings on the surface of a horse-chestnut bough are instructive in connection with both kinds of leaf. The most obvious marks are broad triangular or shield shaped depressions (*L*, fig. 42), which are the scars left by the fall of the foliage-leaves in former years: they occur in alternate pairs, *i.e.* one pair of scars points N. and S., the next E. and W. and so on. The scars are marked near their lower border with a line of dots or raised papillæ[1] which are the scars of the vascular bundles. When the leaf was attached to the plant, the vascular bundles ran from the leaf-stalk into the branch, and when the leaf was cast in autumn, the bundles were broken like the rest of the tissues. At the upper edge

[1] Not to be confused with the lenticels scattered irregularly over the bark.

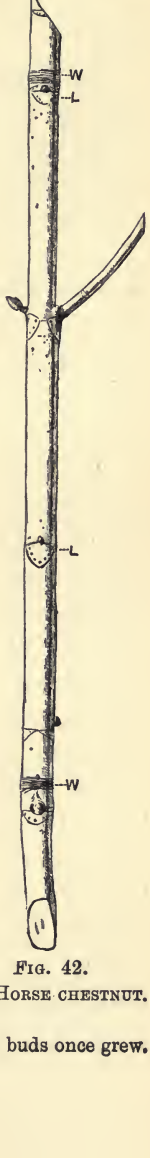


FIG. 42.
BRANCH OF HORSE CHESTNUT.

L, *L*, scars of fallen leaves.
W, *W*, wrinkled places where the scale-leaves of terminal buds once grew.

of some leaf-scars are seen withered undeveloped axillary buds.

At irregular intervals on the branch are seen finely wrinkled places, about $\frac{1}{8}$ inch in length; these are made by the scars of scale-leaves; under a lens the scars can be seen to resemble those of the foliage-leaves, except that they are relatively wider and shorter, and that the scars of the bundles are less evident, or indeed not to be seen. Each wrinkled place represents the spot where a terminal bud once existed, we have therefore evidence of how much the branch grew from year to year. Thus we get by different means the same sort of evidence of yearly growth as is yielded by the annual rings in wood.

The horse-chestnut not only serves as an illustration of foliage- and scale-leaves, it also serves to demonstrate one of the common modes in which foliage-leaves are arranged on the branch. When the leaves grow opposite to each other in a plane at right angles to that in which the pairs of leaves above and below are developed, the arrangement is known as *decussate*. This decussate arrangement is common, but it is by no means the only one, great variety exists in this matter, and a special name, *phyllotaxy*, has been given to this department of morphology. In many plants the leaves are alternate; thus one leaf will be on the north side, then at the next node the leaf will be southerly, then north again one stage higher. In this case the leaves are arranged in two vertical rows: in the horse-chestnut there are four vertical rows, while in other plants a larger number exists. In the groundsel for instance the leaves are in five vertical rows.

This plant may be used to demonstrate the fact of some general importance, that the leaves also form a continuous spiral line round the stem. This double arrangement may be illustrated by a diagram, fig. 43, in which the dots are arranged both in vertical and in oblique rows, the former being the more obvious.

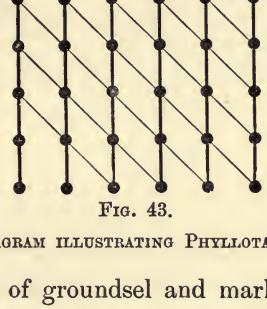


FIG. 43.

DIAGRAM ILLUSTRATING PHYLLOTAXY.

Take a shoot of groundsel and mark the base of any leaf-stalk with a spot of ink by which it may be recognized: the next leaf above will be slightly to the left and the third again to the left, so that a line passing through the 1st, 2nd, 3rd, 4th, &c. leaves in order of height will make a spiral travelling upwards and in the direction of the hands of the clock. When the 6th leaf has been reached it will be found to be vertically over the 1st, which must necessarily be the case when the leaves are in five vertical rows. One other point must be noted; in passing from the 1st to the 6th, the spiral goes twice round the stem. These two facts are expressed numerically by the fraction $\frac{2}{5}$. In the same way the fraction $\frac{3}{8}$ means there are eight vertical rows arranged in a spiral which

goes thrice round the stem, and other arrangements are similarly expressed. The phyllotaxy ($\frac{3}{5}$) of the plantain is shown in fig. 44.

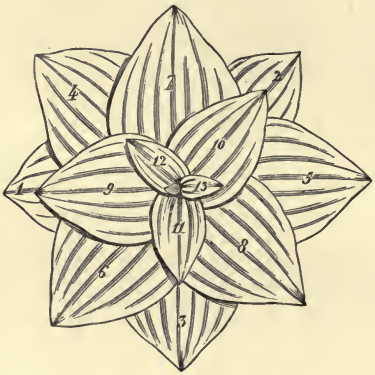


FIG. 44.

PLANTAIN (*Plantago*),

viewed from above to show the $\frac{5}{8}$ phyllotaxy: the leaf-spiral follows the course 1, 2, 3.....13.

From Le Maout and Decaisne.

Form.

The typical form of leaf is flat and thin; that is to say, although many plants have fleshy, cylindrical, or almost spherical leaves, yet the majority have the form familiar to everyone in the leaves of our ordinary trees. The biological meaning of this form is plain enough, the leaf being the assimilating organ which enables the plant to build up organic material, it is necessary that a green surface as large as possible shall be exposed to the light, this will be realised when it is remembered how small is the percentage of CO_2 existing in the atmosphere.

In order to expose a large surface with a small expenditure of material the leaf must obviously be thin, just as gold-leaf, which is required to expose a large area and is of valuable material, is thin. Moreover if a leaf were not thin, some of the cells would be so much shaded by the others that they would be unable to assimilate.

The flat broad part of the leaf is the *blade* or *lamina* (fig. 45), the stalk (which is often absent) is technically known as the *petiole*. At the base of the petiole in many leaves are a pair of outgrowths known as the *stipules* (fig. 45), these are clearly seen in the leaf of the rose, in the cherry, and in the pansy.

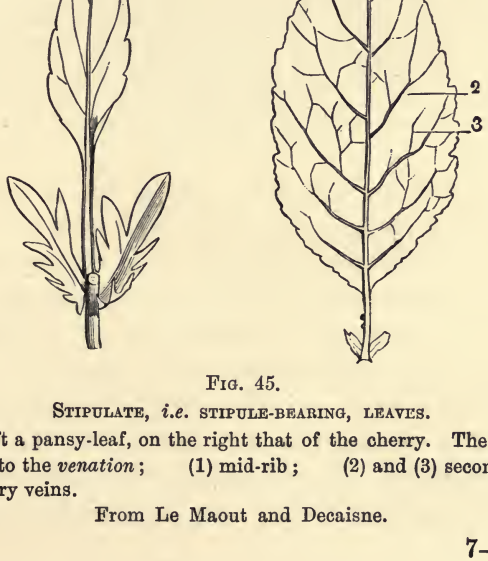


FIG. 45.

STIPULATE, *i.e.* STIPULE-BEARING, LEAVES.

On the left a pansy-leaf, on the right that of the cherry. The numbers refer to the *venation*; (1) mid-rib; (2) and (3) secondary and tertiary veins.

From Le Maout and Decaisne.

A striking feature in the typical leaf is that it is *dorsiventral*, it has a back and a front differing from each other; in the parts of plants hitherto considered this has not been the case, the stem and the root are not dorsiventral but are symmetrical round an axis. In leaves the dorsiventral character is seen in a number of points, even in external characters; thus in many leaves the lower surface is paler than the bright green upper surface, or it may be more hairy or marked by projecting veins. The internal and microscopic structure is even more plainly dorsiventral. Connected with this character is a capacity of growth, a sensitiveness to light by which leaves are enabled to arrange themselves with one particular surface at right angles to the light. To a plant growing freely in the open air the light comes mainly from above, and thus it happens that leaves are more or less horizontal, *i.e.* with the upper surface at right angles to the vertical light. The surface which thus receives most light, and which we usually call the upper surface, is physiologically considered the assimilating surface.

The power of adaptation is clearly seen in a plant so placed that it receives light from one side, the leaves are then twisted and tilted so as to make the most of the light; this may be well seen in a geranium growing in a window, or a tropæolum sprawling out of a flower-box. Leaves vary extremely in shape; what may be called the typical form is well seen in the beech or the laurel, where the stalk is continued as the midrib into the lamina, which spreads out symmetrically on either side. From the midrib a number of "veins" run right and left towards

the edge of the leaf, branching and becoming smaller till the smallest branchlets are only visible to the naked eye by holding the leaf against the light.

The veins are the ramifications of the vascular bundles and therefore contain xylem-vessels. Vessels, it must be remembered, are the water-carriers of the plant, and when it is considered how easily a leaf withers, or in other words how great is its need of water, the fine ramification of the water pipes is not surprising. The leaf may be compared to a country cut up into innumerable minute fields by an elaborate system of irrigation.

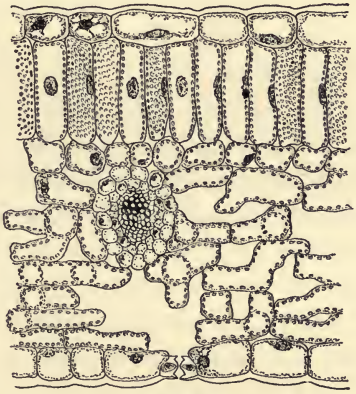


FIG. 46.

TRANSVERSE SECTION THROUGH THE LEAF OF THE HELLEBORE, showing, from above downwards, the upper epidermis, the palisade cells, the spongy tissue (in which a vascular bundle is seen), the lower epidermis, in which is shown a single stoma opening into a large intercellular space.

It must be remembered that the veins not only serve for irrigation but also supply a framework for the support of

the cellular tissue in which the chlorophyll bodies are contained. The cellular tissue or parenchyma of the leaf is known as *mesophyll*, and is one of the points in which the two sides of the leaf differ from each other. On the upper side of the leaf there is, beneath the epidermis, a characteristic layer of cells known as *palisade* tissue, because in a section they look like planks placed side by side to make a paling. The figure (fig. 46) shows this aspect; it also shows that the palisade tissue is the part of the leaf which contains the greatest amount of chlorophyll. The lower half of the leaf is seen in the same figure to be made up of cells of irregular form, so arranged as to leave large spaces among them. Those who have lived in a chalk country must have seen walls built of flints in which the large irregular spaces are filled with mortar. If the mortar is imagined to be air, and each flint a cell, an idea is obtained of the structure of the lower layer of the leaf, which from its loose texture is called *spongy* tissue. It is the presence of the air in the spongy layer which gives the lighter colour to the lower side of many leaves. This may be proved by a simple experiment. A leaf of the lesser celandine, or an arum leaf, is placed in water and a strong inhalation is applied to the cut stalk held between the lips. In this way air is sucked out of the leaf, and water finds its way through the epidermis and takes the place of the air which has been removed. The moment at which it enters is clearly perceptible by the change in colour, the lower surface turning dark green as the water fills up the air spaces in the spongy tissue. If the epidermis is stripped from the lower surface of a

leaf and examined under the microscope, it will be evident by what means the water passed this membrane.

FIG. 47.

THREE STOMATA WITH SURROUNDING EPIDERMIC CELLS (*E*): *G*, *G*, guard cells of a stoma.

Scattered thickly among the ordinary epidermic cells are structures known as *stomata*, shown in fig. 47. Each *stoma* is made of a pair of kidney-shaped cells called *guard* cells, fitting together with their concave sides inwards and leaving an oval cleft by which the intercellular spaces of the leaf communicate with the external air; it should be noted that the guard cells differ from ordinary epidermic cells in possessing chloroplasts. Each stoma is at first a single cell which is divided into two compartments by a cross wall. The cross wall finally splits into two layers between which the opening of the stoma lies. The remarkable form of the guard cells is well seen in transverse section (fig. 46).

The stomata have the power of opening and shutting

in response to changes in the environment of the plant. The mechanism by which they do so need not be described, it must suffice us to know that when the plant begins to suffer from want of water, or when it is exposed to some other conditions, *e.g.* darkness, the cleft between the guard cells, and therefore the passage from the outer air to the intercellular spaces of the leaf, is closed. The most important function of the stomata is the aeration of the inner parts of the leaf. And since it is through the stomata that the CO_2 enters the leaf, these organs are of great importance in the nutrition of the plant. But they also influence the degree to which the leaf loses water by evaporation—a function known as *transpiration.*

Transpiration.

If a delicate leaf is gathered on a hot, dry day, it withers almost immediately, that is, its cells collapse for want of water in the manner already described. This shows two things, (1) that leaves are constantly losing water by evaporation, (2) that, since the leaf does not wither if left on the tree, the loss of water is, under normal circumstances, continually made good.

The means by which a current of water is carried from the root to the top of a high tree is still an unsolved problem. There are however certain fundamental experiments which must be considered.

If a branch, such as that of a laurel, be cut and placed in a coloured fluid, *e.g.* eosin dissolved in water, and left there for some hours, it will be seen that the coloured fluid has travelled up it, showing that there is a sucking

power of some sort in the branch and leaves. The bark will not be coloured, and if the branch be peeled, the contrast between the white inside of the peel and the wood stained pink with eosin is striking. The fact that the fluid travels in the xylem is still better seen in a young succulent stem where, on splitting the plant, the vessels filled with eosin show out as delicate pink streaks.

There are various arrangements by which we can accurately measure, from minute to minute, the amount of water which a cut branch is absorbing. With an instrument of this sort it is easy to prove that the amount of absorption depends on the amount of evaporation going on from the leaves. Thus if the leaves are placed under a bell jar, and therefore in damper air, the instrument records the fact that the absorption is less, and the readings quickly rise again when the bell is removed. The absorption may be diminished by cutting off some of the leaves and thus diminishing the total amount of evaporation. In this sort of way it can be shown that the water-supply of a leaf by the vessels is a self-regulating mechanism; that rapid evaporation increases the upward current, so that the greater the loss the greater is the supply.

In thinking about the transpiration from a leaf surface it must be remembered that the evaporating surface is much greater than the surface which is visible, because the spaces in the spongy tissue communicate with the outer air through the stomata, so that the surface of each constituent cell of the spongy tissue evaporates, not so much as though it made part of the external surface, but

still considerably. It will be more easily realised how porous a thing the epidermis must be, when it is remembered that there are thousands of stomata on a square inch.

Leaf-fall.

That the leaves of many trees fall from the tree in autumn is a familiar fact, but the physiology of the process is not so well known. It is easy to prove, by a simple experiment, that leaf-fall is a process requiring a certain mechanism for its accomplishment, that it is not a

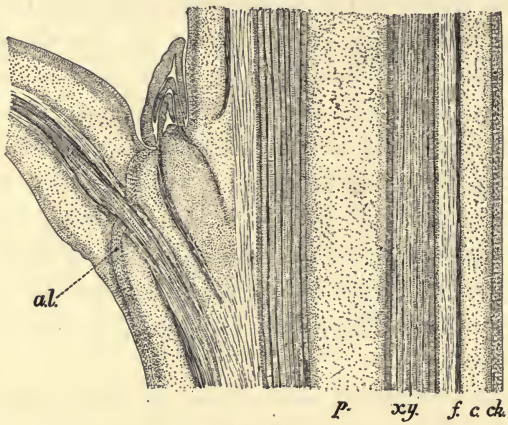


FIG. 48.

LONGITUDINAL SECTION THROUGH A BRANCH AND PART OF A LEAF-STALK OF THE POPLAR (*Populus*).

The *absciss* layer and a layer of cork are shown at *a.l.*

ck, cork; *c*, cortex; *f*, bast fibres; *xy*, xylem; *p*, pith.

mere tumbling down of withered leaves. If, during the summer, a branch is half-broken so that it hangs on to the tree by its bark only, its water-supply is cut off and it soon withers and dies. It might have been expected that these withered leaves would fall more easily than normal leaves,—but precisely the reverse is the case: they hang on to the tree after all the healthy leaves are cast. This suggests that leaf-fall is an active, not a passive process, a phenomenon of life which can only occur in a living leaf-stalk. This is the case: the leaf falls because a layer of cells (*the absciss layer*) forms across the base of the stalk specially adapted to allow the leaf to free itself. Beneath this layer cork cells are developed, which serve to cover and protect the wound left by the fall of the leaf.

CHAPTER VIII.

ASEXUAL REPRODUCTION—PLEUROCOCCUS—MUCOR—CONJUGATION—MUCOR—SPIROGYRA.

THE present chapter deals with a part of physiology hitherto hardly touched on, namely, reproduction. Every organism in the world is subject to a variety of risks, and is constantly in danger of being destroyed: in the case of the animal kingdom the preying of one animal on another, and the contest among animals of the same species for food are familiar, but we are apt to forget that the struggle for life is quite as severe among plants. The external dangers are evident enough, slugs decimate seedlings, and other and larger animals find their food among plants; while countless parasites—funguses and insects—live on them: plants struggle with each other to get the best of the light: and they have the severities of climate, cold and drought, to contend with. Given the fact that plants are subject to a struggle for life, reproduction at once becomes of interest, for it is those species which produce the best adapted offspring, in sufficient number to make up for the constant destruction, that will survive. So that the ways in which a plant can produce vigorous

and numerous offspring come to be the most important part of its physiological equipment.

The value of reproduction comes out clearly in those plants which regularly exhaust themselves by yielding seed and die in the process of reproduction. This is the case with annuals, which start as seedlings in the spring, yield seed in the autumn and then die. It is clear that seed-production is what kills them, because if they are prevented from setting seed, they will survive. Here the individual is sacrificed to the good of the community: the species (or group of individuals) lives on in the seeds, while the individual plants die. All the machinery of the individual, its manufacture of organic material with the help of chlorophyll, and its consequent storage of starch and other reserve material, are directed to the very thing which kills it, *viz.* the production of a big seed crop. The life of the species is the really important thing, the life of the individual is important because it renders reproduction, *i.e.* the continuance of the species, possible. This sounds paradoxical, but I believe the machinery of living things to be more comprehensible if it is thought of as being directed to the preservation of the species rather than of the individual.

Some forms of reproduction are comparatively simple. In the tulip-bulb a bud developes in the axil of a leaf, exhausts the old bulb, and carries on the life of the plant. Again in the bramble the branches in autumn grow down to the ground and put out adventitious roots, and in the spring the bud at the end of the branch shoots out anew. Again many water plants habitually detach parts of their

stems which float away and make new plants. These forms of reproduction are precisely the same as the artificial continuance of species practised by gardeners, in making cuttings. In none of these cases does the question of sex enter into the problem. The river-weed, Elodea, which has spread in this way throughout the rivers of England, consists entirely of female plants; and the same thing might have happened if the original parent plant had been a male. For this reason these modes of reproduction are classed together as asexual or vegetative.

It will be seen later that many plants produce separate and special cells which serve for asexual reproduction. Such cases help us to realise that asexual reproduction is quite as mysterious and wonderful as sexual reproductions. The essence of the thing is that in a single cell there should be locked up the potentiality of a future plant, *i.e.* that a single cell should be able to grow into a perfect plant; and that this should be possible is equally wonderful, whether the new growth originates in an asexual reproductive cell or an ovum.

The difference between the two is that the egg-cell does not normally develope until it has been fertilised (*i.e.* infected or stimulated) by being fused with the male element, whereas the asexual reproductive element requires no such treatment.

Pleurococcus.

When an organism is simple in structure, when for instance it consists of a single cell, asexual reproduction may be, as far as observation is concerned, a perfectly

simple process. One example has been considered in the case of yeast, where a young cell buds from the parent and becomes a new plant. Here, and in similar cases, growth cannot be distinguished from reproduction. A cell gets bigger by means of *growth*,—the process becomes *reproduction* when the increment breaks loose from the parent. This comparison does not by any means make reproduction easier to understand, it merely shows that in growth the mystery of reproduction is really present.

The green dust found on the trunks of trees is made up of countless millions of the plant Pleurococcus: like yeast it is a unicellular plant, but instead of being a unicellular fungus it belongs to the great class of chlorophyll-containing plants. It obtains its food from the air, and from the water trickling down the tree. Its manner of nutrition is like that of other green plants and need not be further considered. Under the microscope it is seen to consist of minute green cells, more or less massed together in clusters, and presenting a number of different stages of cell division. A single cell divides by a cross-wall into two compartments, then into four, and then into eight. Various intermediate stages are to be found, and it can also be seen how the compartments, into which the parent is divided, disintegrate into their component cells, which finally fall apart.

Mucor.

For a study of specialised asexual reproductive cells Mucor, one of the many fungi known as moulds, is

convenient. Mucor like other fungi is devoid of chlorophyll, it does not earn its own living, but depends, like yeast, on the material previously built up by some other organism. Ripe fruit, jam, bread and other similar things, when left to themselves and kept warm and damp, become covered with a crop of some kind of mould. Such a result is practically universal, because the reproductive cells or *spores* of the mould, being small and light, float in the air and are universally distributed; they settle like dust on everything, and thus chance on the organic materials which can support them. The spore germinates, that is, it begins to grow and to take on the form of a delicate tube known as a *hypha*. The hypha grows, branching as it elongates, and covers the substratum with a delicate colourless web or fluff made up of countless interwoven tubes, sending other branches like roots into the substance on which it lives. This irregular web of branching tubes constitutes the whole of the absorptive part of the plant and is collectively described by the term *mycelium*. The most remarkable point in its structure is that it is not made up of a regular series of cells; it has occasional cross-walls, but it is not divided into the numerous small compartments or cells seen in the plants previously studied. There is little to be seen in the hypha except oily protoplasm containing vacuoles: by the use of staining reagents numerous small nuclei can be seen.

After a time other structures make their appearance:—minute rods grow vertically up in the air, each crowned with a little ball, and looking like small round-headed pins. These are called *spore-bearing hyphæ*, and the pin

heads (in which the spores are produced) are called *sporangia*. The sporangium is originally a swelling at

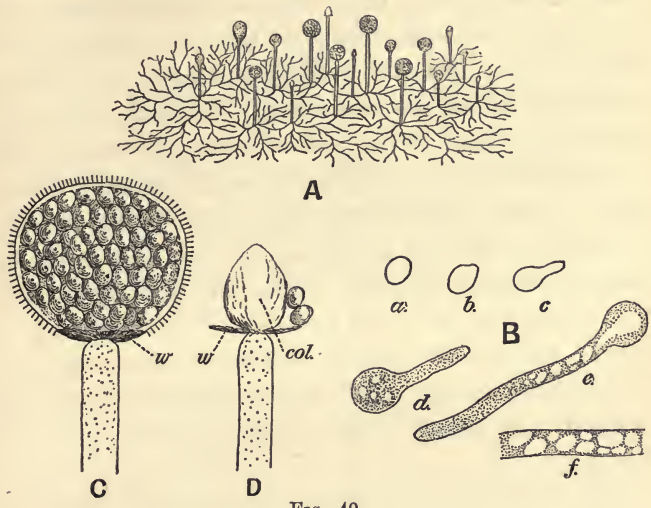


FIG. 49.

MUCOR.

A. Diagrammatic sketch showing the mycelium and the sporangia borne on vertical hyphæ.

B. Various stages in the germination of a spore; *f*, mycelium with vacuoles.

C. A ripe sporangium containing spores, and covered with a coating of calcium oxalate crystals; *w*, the collar.

D. A burst sporangium; *col*, the columella to which two spores adhere; *w*, the collar.

the top of a hypha cut off from the rest of the mycelium by a cell-wall. The contents of this terminal cell become separated into a large number of small masses of protoplasm, and these when they have clothed themselves with cell-walls are the spores. But before this a change takes place in the cross-wall at the base of the sporangium:

it grows and bulges into the cavity of that receptacle, filling up a great part of its cavity and forming a structure known as the *columella* (see fig. 49). The protoplasm, remaining over after the development of the spores, degenerates into a slimy gelatinous substance in which the spores are embedded. The wall of the sporangium becomes brittle and is covered externally with a coating of minute crystals of calcium oxalate. After a time the wall of the sporangium breaks by the swelling of the jelly, and the spores are set free. In this stage the sporangium presents a characteristic appearance: the remains of the wall look like a broken fringe or cup at the top of the stalk or spore-bearing hypha, and is called the *collar*: and on the columella (now fully exposed) are usually seen a few scattered spores adhering.

The cycle has now been completed, the spores will germinate, they will give rise to a fresh mycelium, bearing sporangia which contain spores; and thus the plant may be indefinitely reproduced.

Mucor. Sexual reproduction.

Mucor also has a simple form of sexual reproduction. In the higher plants, as in animals, the male element is a structure strikingly different from the egg-cell, which it fertilises. This is obvious in animals where the spermatozoid is the fertilising agency; also in the fern where a similar motile male element, the antherozoid, conveys the fertilising element to the egg-cell. But in Mucor there is no such differentiation, the act of fertilisation is

the coalescence of two similar *protoplasts*[1]. When this is the case the process is known as *conjugation*, but it must be recognised that it is essentially a sexual process.

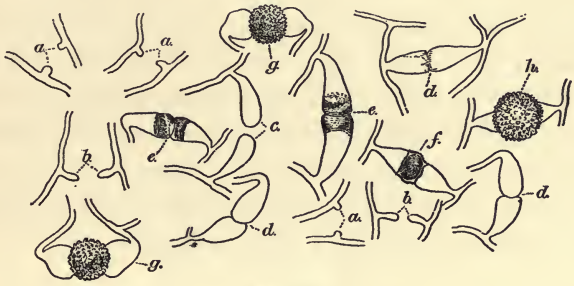


FIG. 50.

CONJUGATION OF MUCOR.

a, *b*, *c*, *d*, *e*, *f*, *g*, represent successive stages; *h*, fully formed zygospore.

The first thing that can be seen is the approximation of two branches of the mycelium which are richly provided with protoplasm, and which finally meet by their swollen ends (see fig. 50). The next stage consists in the formation of a cross wall in each branch, and finally the collections of protoplasm thus isolated are allowed to meet by the degeneration of the ends of the branches. There is thus formed a central cell containing the united contributions from the conjugating mycelial branches. This cell is known as the *zygospore*; it is characterised by a rough, dark-coloured outer coat, and it remains attached to the now empty mycelial branches, which are sometimes

[1] Protoplast means the protoplasmic contents of a single cell.

called *suspensors*—an unnecessary term. The zygospore is endowed with a certain persistence of vitality, so that after the crop of Mucor has died and disappeared, the zygospore is left alive, isolated in the nutritive substratum. After some weeks of rest it germinates, *i.e.* begins to grow. The thick outer coat bursts and the inner cell-wall grows out into a stout mycelial tube or hypha. This hypha may either at once proceed to form a sporangium, or it may branch once before it does so, but in any case it does not form a complex web of mycelium like that produced from a sporangial spore.

Spirogyra. Conjugation.

Spirogyra (as described in Chapter I.) is an Alga, having the form of a delicate filament, each filament being made up of a simple row of cells. The process of conjugation takes place between the cells of neighbouring filaments. A number of cells in each of the filaments put out processes, simple tubular outgrowths from the cells, which meet, coalesce and finally become converted into tubes uniting cell to cell as shown in fig. 51. The contents of the conjugating cells contract and the rounded masses so produced are the elements which fuse together in the act of conjugation. The balling of the protoplasm begins in one of the conjugating cells before it is perceptible in the other. The protoplasts which are thus early in contracting have a certain masculine character, inasmuch as they are more active than the protoplasts with which they conjugate. They travel through the connecting tube and by fusion with the stationary protoplasts they form *zygospores.*

The zygospore clothes itself with a thick resisting cell-wall, and after a period of rest germinates and gives origin to a new Spirogyra filament.

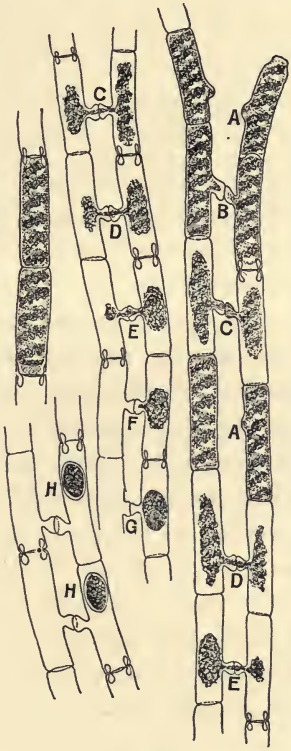


FIG. 51.

SPIROGYRA.

A—*G*, represent various stages in the process of conjugation.
H, fully formed zygospores.

Note the loop-like folds in the cross-walls; they are connected with the mode of growth of the cells.

CHAPTER IX.

ALTERNATION OF GENERATION—THE BRACKEN FERN (PTERIS)—STRUCTURE OF THE SPOROPHYTE OF PTERIS.

Alternation of generation.

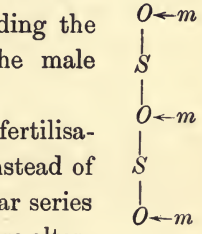
The study of the fern is introduced in this place because of the remarkable manner of reproduction—known as *alternation of generation*—which this plant presents. Alternation of generation is especially interesting because it gives a key to the relationship of the higher plants, such as the sunflower and the oak, which are known as Phanerogams, to the great class of which the fern is one, known as Cryptogams. The knowledge of the process enables us to form a guess at the line of descent of the flowering plants, thus for instance it tells us that they have probably been evolved from fern-like plants. To the professed botanist this speculation is of the greatest value. He studies all plants, and it is this kind of knowledge which enables him to classify them in a rational manner. The subject cannot have this sort of interest to the elementary student. I have therefore determined to treat alternation of generation only from a general point of view, as a remarkable form of reproduction,

and not to insist in any detail on the connection between it and the reproduction of Phanerogams.

The fern exists under two quite distinct forms, as different in appearance as the caterpillar and butterfly; these two forms may for the moment be called *S* and *O*. The alternation of generation consists in this: both *S* and *O* have reproductive organs, but *S* only produces *O*, and *O* only produces *S*. So that the pedigree of a fern would be represented by

O
S
O
S
O

The process is further remarkable for the working together of two types of reproduction, sexual and asexual. The essence of sexual generation is that a cell, the ovum or egg-cell, is fertilised by a male cell which unites or melts up with it, and the fertilised egg-cell thus becomes capable of developing into an embryo or young plant. The essence of asexual reproduction is that the parent produces a cell which developes into a young plant without being stimulated by a process of fertilisation. In the fern, the form *O* bears an egg-cell which when fertilised developes into *S*; *S* produces, without a sexual process, certain reproductive cells called *spores*, and these produce the form *O*. The pedigree may thus be amplified by adding the letter *m* to express the union of the male element.



The diagram shows that the act of fertilisation is confined to the form *O*, so that instead of there being (as in quadrupeds) a regular series of sexually produced generations, there are alternate sexual and asexual generations.

The form *O* is known as the *Oophyte*[1] or egg-bearing plant; it is a minute moss-like organism which no one would suspect of being a fern, and is commonly to be found growing in the flower-pots in ferneries.

The form *S*, known as the *Sporophyte* or spore-bearing plant, is what is familiarly known as the fern plant.

In the next chapter the details of the reproductive acts by which oophyte produces the sporophyte and *vice versa* will be considered. We now pass on to the general structure of the sporophyte.

Sporophyte of Pteris, the Bracken Fern.

The part which we see above ground, with an upright stalk subdividing and bearing leaflets, is a leaf; the stem from which it grows is underground and, as in the case of the sedge (fig. 6), is called a rhizome.

The subterranean stem creeps horizontally below the surface and sends up leaves year by year. The fern serves as an example of a manner of life differing from those hitherto studied, and one that is common among plants. The sunflower is an annual, dying down after it has borne fruit, and beginning next year's cycle in the seedling stage. The oak is a woody perennial,—in which the parts above ground are permanent. The fern is a herbaceous perennial,—in which the parts above ground (the leaves) behave like the stems of annuals and die down to the level of the ground; but they differ from the leaves of annuals in springing from a stock or perennial underground stem.

[1] The term *gametophyte* is commonly used as an equivalent for *oophyte*.

Physiologically the manner of life of the fern is similar to that of such flowering plants as pæonies, larkspurs, columbines and other garden perennials, as well as bulb-plants, tulips, daffodils, &c. It is a manner of life especially well adapted to withstand severity of climate—for the perennial stock is hidden away underground safe from frost and drought.

The rhizome of Pteris is shown in fig. 52, it is a rough looking, irregularly branching stem which grows

FIG. 52.

HORIZONTAL UNDERGROUND STEM OR RHIZOME OF *Pteris*.

G, the growing point; L_1, a developing leaf; L_2, the leaf of the current year; L_3, a decayed leaf of the previous year. The rhizome bears adventitious roots; from L_2 a young rhizome *B* is growing.

more or less horizontally. It ends in a conical point, the growing point, which resembles the growing point of

a sunflower in being a place where cells are manufactured by cell-division, but it differs from it in certain details which need not be considered.

The leaves come off right and left from the rhizome and bend up to emerge above ground. A rhizome, dug up in autumn, will show leaves in various stages; at the basal end, *i.e.* away from the growing point, are the dead and withered stalks of last year's leaves, and nearer the apex come the present year's leaves, nearer still are very young leaves which will remain dormant through the winter and shoot up in the following spring. The most noticeable point about the young leaves is that the stalk is strongly developed while the lamina is small and folded down on the top of the stalk. Two other facts must be noted: namely, that buds are formed on the leaf-stalks; and that the rhizome bears adventitious roots—the original true roots having long ago disappeared.

Pteris. Histology.

The histology of the rhizome is interesting because it supplies a type of vascular bundle differing from anything previously described.

The characteristics of the bundle in the sunflower and oak are two: (i) it possesses in its cambium the power of increase in thickness: (ii) xylems and single strands of phloem run side by side; these features are technically expressed by calling the bundle *open* and *collateral.* In Pteris the bundle is *closed, i.e.* the cambium is absent, and there are two layers of phloem running with the xylem and almost surrounding it.

In a transverse section of the rhizome we have externally the epidermic layer, which presents no special

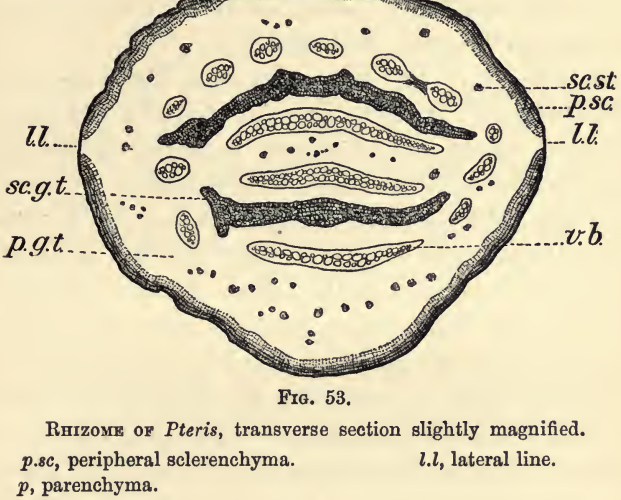


FIG. 53.

RHIZOME OF *Pteris*, transverse section slightly magnified.

p.sc, peripheral sclerenchyma. *l.l*, lateral line.
p, parenchyma.
sc, sclerenchyma.
sc.st, scattered strands of *sc*. *v.b*, vascular bundle.

points of interest, and from a physiological standpoint it is unimportant, for the protective function is practically taken over by a layer of hard-walled *sclerenchyma*. This layer makes a dark-coloured border round the section as seen with a low power (fig. 53); it is wanting at two opposite points where the subjacent tissue comes to the surface. These places are visible as streaks running down two opposite sides of the rhizome and are known as *lateral lines*. Their function is believed to be connected with aeration. In the cork of the oak stem and of the potato tuber are certain spots known as *lenticels*, where the

cork-cells are loose and traversed by intervening spaces, through which the internal parts of the stem receive air. So that the lateral lines of the rhizome, although of different morphological value, would seem to have the physiological character of lenticels.

The inside of the section presents three obviously distinct tissues. It has patches and dots of a dark colour and hard consistence which are irregular strands and plates of sclerenchyma running longitudinally. Secondly, there are yellowish spots of rounded or oval outline. These, the vascular bundles, are not arranged regularly, although they make, with the larger sclerenchyma bands, a more or less defined mass in the section. The rest of the rhizome is made up of soft pith-like parenchyma.

These various tissues must be examined in detail. The cells of the sclerenchyma are many times as long as broad, and fit close together without intercellular spaces. The walls are lignified, and have simple oblique slit-like pits.

The soft parenchyma is made of polygonal cells roughly hexagonal in transverse section, with cellulose walls not fitting closely together, but leaving intercellular spaces. It is this tissue which comes to the surface at the lateral lines.

The parenchyma cells are crowded with starch grains and serve as the storehouse of the rhizome.

Vascular bundles[1].

Each bundle is surrounded by a *bundle-sheath* or *endodermis* consisting of a single layer of small cuticu-

[1] See Preface on the word *stele*.

larised brown-coloured cells, which in longitudinal section are seen to be only slightly elongated; they do not contain starch.

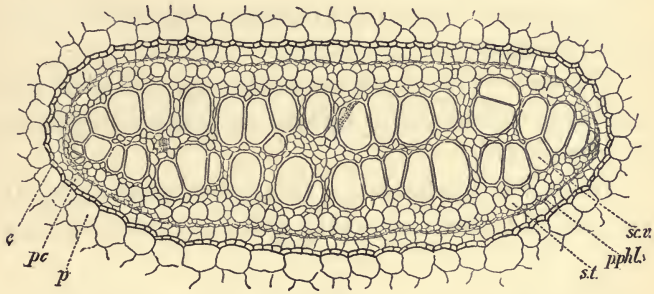


FIG. 54.

TRANSVERSE SECTION OF A BUNDLE IN THE RHIZOME OF *Pteris*.

e, endodermis, outside which is parenchymatous tissue *p*.
p.c, pericycle. *p.phl*, protophloem.
s.t, sieve-tube. *sc.v*, scalariform vessel.

Inside the bundle-sheath is an irregular layer of colourless softer cells, which differ from those of the bundle-sheath in containing starch: these form the *pericycle*. The rest of the bundle is made up of the same two main classes of tissue as those seen in the sunflower and oak, namely, xylem and phloem: the centre of each bundle is xylem and is surrounded, not completely but on two opposite flanks, by the phloem. There is no cambium.

What was said in an earlier chapter as to the general characteristics of vascular tissue, holds good in the case of the fern.

Both xylem and phloem contain vessels and parenchyma.

In both the vessels are built up of elongated cells one overlapping the next.

The xylem vessels have lignified walls and no protoplasmic contents.

The phloem vessels, or sieve-tubes, have cellulose walls and intercommunicating threads of protoplasm piercing the sieve-plates.

Inside the pericycle is a layer of small cells, the *protophloem*[1], and inside this again is a layer of large

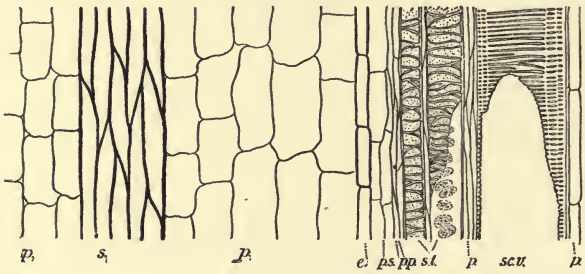


FIG. 55.

LONGITUDINAL SECTION OF THE RHIZOME OF *Pteris*.

p, parenchyma.
e, endodermis.
p.p, protophloem.
sc.v, scalariform vessels.
s, sclerenchyma.
p.s, pericycle.
s.t, sieve-tubes.

[1] In the rhizome of Pteris the protophloem is sometimes continuous all round the bundle, although the fully developed phloem is discontinuous and does not completely surround the xylem.

sieve-tubes. In the fern the sieve-tubes differ from the typical sieve-tubes of the flowering plants in which a large transverse sieve-plate separates two contiguous elements. In the fern the sieve-plates are on the longitudinal walls, and are therefore most easily seen in longitudinal section. Fig. 55 shows irregular elongated areas of a granular, or faintly dotted aspect, which are the sieve-plates pierced by strands of protoplasm passing from one element to the next.

Inside the phloem are the vessels of the xylem im-

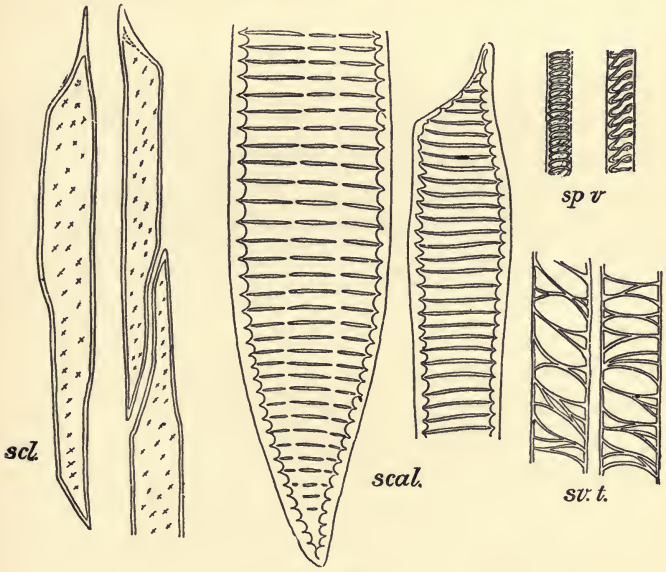


FIG. 56.

MACERATED RHIZOME OF *Pteris*,
showing the isolated elements.

scl, sclerenchyma. *scal*, scalariform vessels.
sp.v, spiral vessels. *sv.t*, sieve-tubes.

bedded or packed as it were in a small quantity of parenchyma. There are a few minute spiral vessels (not shown in the figs. 54, 55), but the great mass of xylem vessels are of large diameter and are known as *scalariform vessels.*

The scalariform, *i.e.* ladder-like character of these vessels comes out clearly in longitudinal section. The horizontal markings which represent the rungs of the ladder are thickenings of the walls.

CHAPTER X.

REPRODUCTION OF THE FERN—SPORANGIA—PROTHALLUS —EMBRYOLOGY.

Sporangia and spores.

The plant of which the general structure has now been described, and which is known as the *sporophyte*, bears certain reproductive cells which are called *spores*. The development, and structure, of the spores, must now be given in detail, together with the history of their germination; this will be followed by an account of the *oophyte* to which the germinating spore gives rise.

The spores (as in the case of Mucor) are found in receptacles—*sporangia*—of which a group is shown in fig. 57. The sporangia grow in groups and patches known as *sori*, which in the majority of ferns are found on the lower surface of the leaves. Each sorus is protected by a covering,—the *indusium*. In Pteris the indusium is the edge of the leaf folded back so as to roof over the linear sorus running down the marginal part of the leaf. In Aspidium it is a specially developed membrane covering the sorus like an umbrella, and therefore

differing morphologically from the indusium of Pteris. Fig. 57 shows that the sporangia arise from a cushion (the *placenta*), which is simply a swollen vein.

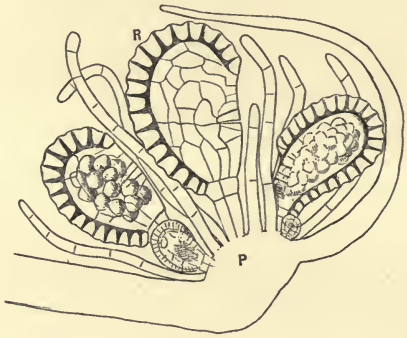


FIG. 57.

TRANSVERSE SECTION THROUGH A SORUS OF PTERIS:

P, the placenta, bearing hairs and sporangia, two of which contain spores: *R*, the annulus or ring of the large empty sporangium.

The sporangium consists of a hollow head mounted on a delicate stalk. Within the cavity of the head are contained numerous minute brown cells, which are the spores. The spore-wall is differentiated into two layers, an inner cellulose membrane and an external cuticularised layer, resembling in fact the outer wall of an epidermic cell. To understand the development of the spores it is necessary to have a general idea of the development of the sporangium.

Each sporangium is the product of a series of cell divisions occurring in a single epidermic cell. This mode of development gives a certain morphological value to a sporangium, which is technically expressed by saying that

the sporangium of the fern is a *trichome, i.e.* a hair-like structure; the multicellular hairs which occur on the surface of many plants being each similarly developed from a single epidermic cell.

The chief stages in the development of the sporangium are shown in fig. 58. The epidermic cell divides into a stalk and a head, which are the parent-cells of the stalk and head of the future sporangium. The stalk cell

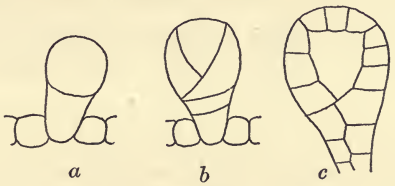


FIG. 58.

DEVELOPMENT OF THE FERN SPORANGIUM.

a. The out-growth from an epidermic cell is divided into two cells; a rounded apical cell giving rise to the head of the sporangium, and a basal cell from which the stalk is developed.

b. Two out of the four oblique walls, by which the *archespore* is marked out, are shown.

c. A third oblique wall has appeared, and the wall of the sporangium is seen to be developing.

divides by numerous cross-walls and comes to consist of several stages or storeys one over the other, each layer consisting of four cells. The fate of the head-cell is more complex: it will be enough to say that by four cell-walls (of which two are shown in fig. 58, *b*) a large triangular cell, the *archespore*, is marked out in the middle of what was once the headlike half of the original epidermic cell. From part of the archespore what are known as the

mother-cells of the spores develope by cell division, and finally each mother-cell divides into four spores.

The development of the sporangium and spore is here given in an abbreviated and diagrammatic manner, and the formation of what is known as the *ring* or *annulus* (fig. 57) has been left out. It is a line of strong cells running like a crest three-quarters of the way round the head of the sporangium. These cells are sensitive to changes in the dampness of the air; when they are dried the ring tends to uncurl and exerts a tearing force on the thinner parts of the sporangium wall, which gives way under the strain in the form of a gash or cleft running across it. The place at which the sporangium opens will be understood from fig. 57 (*R*) in which the cleft is not quite closed. Through this gash the spores are able to escape, and here their small size and lightness comes in as a valuable quality, since they are borne on the wind like dust, so that some at least, out of the great quantity produced, hit on situations suitable for their future growth. In the laboratory spores are sown on peat, or better still on tiles, where they grow well and handily.

With regard to the germination it will suffice to know that the spore increases in size, and by the formation of cross-walls becomes a cellular body instead of a single cell. Fig. 59 *b* represents an early stage in the germination, or in other words it represents a very young oophyte. The upper part *p*, consisting of two cells, is green from the presence of chlorophyll and carries on the work of assimilation, while the lower, thinner part *r.h.* is colourless and is a root-like organ or root-hair. Thus in the earliest

stages the young oophyte is differentiated into a green aerial or assimilating part and terrestrial root-like part. The green part now grows and by a series of cell divisions

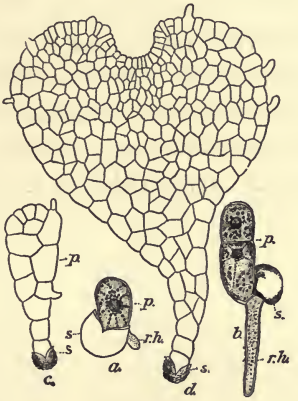


FIG. 59.

DEVELOPMENT OF PROTHALLUS FROM THE SPORE.

a, germinating spore; *s*, the cell wall of the spore; the new growth has already divided into *r.h.*, a root-hair and *p*, which contains chloroplasts and by further division forms the prothallus.

b, *c*, *d*, older stages, *c* and *d*, less highly magnified.

a and *b*, *Dicksonia antarctica*, *c* and *d*, *Aspidium filix mas*.

(After Luerssen.)

forms a flat, heart-shaped body, which is known as a *prothallus*. The central part of the prothallus is thickened into a cushion-like ridge several cells in thickness, the rest of the expanse consists of a single layer of cells. It grows with the cushioned side downwards attached to the soil by numerous root-hairs and is now a full-grown oophyte leading an independent life, and as above pointed out, of a form extremely distinct from that of the sporophyte which gave it birth.

Sexual reproductive organs.

These are of two kinds: the *archegonia,* which contains the egg-cell, and *antheridia,* in which the male elements are developed. The archegonia (fig. 60) are found near the notched end of the prothallus and on its under surface. Each archegonium consists of a rounded cavity sunk in the tissue of the prothallus and contains the egg-cell: the cavity of the archegonium communicates with the outer world by a *canal,* a curved chimney-like tube projecting

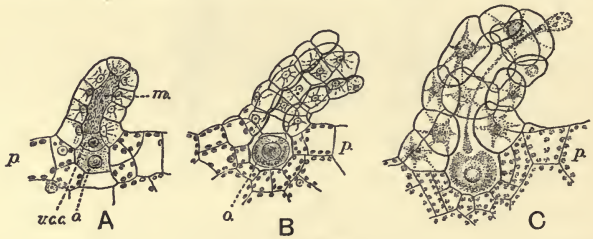


FIG. 60.

A. YOUNG ARCHEGONIUM OF THE FERN (*Polypodium vulgare*).

B. THE SAME MATURE AND OPEN.

C. THE EXPULSION OF THE SLIME AT THE MOUTH OF THE ARCHEGONIUM (in *Pteris serrulata*).

p, p, cells of the prothallus; *o,* egg-cell; *v.c.c.,* ventral-canal-cell *m,* neck-canal-cell. (After Strasburger.)

beyond the surface of the prothallus. This canal is seen in section to be made up of four rows of cells, as though a chimney were built of tiers of four bricks each. In the immature archegonium the free end of the canal is shut, and its cavity is filled up by a long cell or cells called *neck-canal-cells.* Between this and the egg-cell at the bottom is another cell called the *ventral-canal-cell,* which fills up the rest of the cavity of the archegonium.

When the archegonium is fully ripe the canal-cells break down into mucilage, which swells and bulges out at the opening now formed at the free end of the canal by the separation of the terminal tier of cells.

The antheridia (fig. 61) are small green papillæ (which afterwards become brown) found principally among the root-hairs, and further from the notched end of the prothallus

FIG. 61.

A. MATURE ANTHERIDIUM OF A FERN (*Polypodium*) AND CONTAINING NUMEROUS MOTHER-CELLS OF ANTHEROZOIDS. Chloroplasts are visible in the cells constituting the wall of the antheridium.

B. AN ANTHEROZOID.

C. THE ANTHERIDIUM BURST AND EMPTY.

(After Strasburger.)

than are the archegonia. Their architecture is very remarkable. Each antheridium is built of three cells: one forms the roof, and the remainder form the circular walls which limit the cavity within. Imagine a piece of india-rubber tubing bent into a ring by the union of its ends: if such a ring be placed on the table it will make a low circular wall which may be doubled in height by the superposition of another similar ring. This is precisely the structure of the antheridium, its wall is made up of two hollow, ring-like cells with a third flat cell on the top.

Within the cavity a number of spherical cells are seen, and inside each of these is developed one of the male elements known as *antherozoids*, motile organisms resembling the spermatozoa of animals. The antheridium bursts by the rupture of the lid-cell, and its contents, the rounded cells, escape. The process of bursting only takes place when the antheridium is wetted, as for instance with rain or dew in a state of nature, or under the coverglass in the laboratory. Water has moreover a special effect on the rounded cells, which are rapidly disorganised, and thus set free the antherozoids, which swim about in the water. Each antherozoid (see fig. 61) is a tapering rod bent into a corkscrew, and bearing at the smaller end where the coils of the spiral are closer a number of long cilia, by means of which it swims[1].

Antherozoids are found in certain water plants, for instance in the stone-worts Chara and Nitella, and here it seems a natural and fitting adaptation that the male element, which has to find its way to the egg-cell, should be a swimming organism. But that in a land plant the male element should be forced to swim to the egg-cell is remarkable. It seems only possible to explain it as an inheritance from an aquatic ancestor; just as the gill-clefts of the mammalian embryo are such inheritances. Biologically the fact is of interest for it seems to throw a light on the mode of life of the prothallus. We can understand the advantage which the prothallus gains from its habit of growth, clinging as it does to the soil

[1] Each antherozoid bears a protoplasmic vesicle of unknown function.

and thus making a damp chamber in which a film of water, coating its lower surface, may persist until the antherozoids have swum to their destination. That the antherozoid does reach the egg-cell is not a mere matter of chance. The slime which fills the cavity of the canal of the archegonium contains *malic* acid, and it has been shown that the antherozoids are attracted by this acid. If a capillary glass tube containing malic acid is introduced into a drop of water in which antherozoids are swimming, these organisms are found to direct their course towards the tube and to force their way into the opening. In the same way they force themselves into the slime in the canal and ultimately make their way to the egg-cell, which they fertilise.

The fertilised egg-cell divides and subdivides and grows into a complex of cells,—an *embryo* or young plant. This young plant is the sporophyte, the plant which will bear sporangia, will produce spores and will thus complete the cycle of development. It is not necessary to give a complete account of the process of cell division by which the embryo grows out of the egg-cell. It will be enough to know that the first-formed cell-wall is more or less parallel to the axis of the archegonium and divides the egg-cell into an anterior and a posterior half. From the anterior half the young stem and the first leaf are developed, from the other half are formed the primary root and a structure known as the *foot*. The foot has an important function, for it is by means of it that the embryo sporophyte is nourished in the early stages of its existence. The prothallus has finished its share in

the life-history of the plant and is of no further use except as a supply of food material for the embryo; and this supply is drawn by the foot acting like a sucker or root.

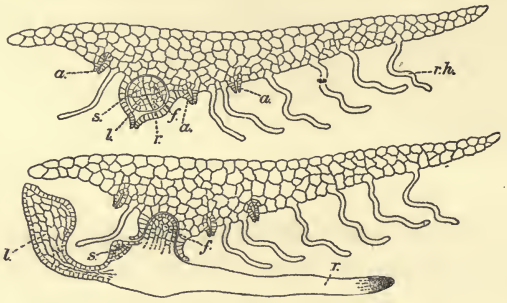


FIG. 62.

DEVELOPMENT OF THE SPOROPHYTE OF THE FERN FROM THE EGG-CELL, diagrammatically represented.

In the upper figure the embryo is made of a number of cells, the four thick lines represent the cell-walls by which the egg-cell was partitioned in the early stages.

Of these four cells, *s* and *l* develope into stem and leaf;

r and *f*, into root and foot, as may be seen in the lower figure.

a, *a*, unfertilised archegonia.

rh, root-hairs on the lower surface of the prothallus.

The embryo is contained in a swollen and distorted archegonium.

(After Mangin.)

We thus get this remarkable state of things; that the developing sporophyte remains attached, by an absorbing organ, to the oophyte which gave it birth; the sporophyte lives in fact like a parasite on its parent. This arrangement is only temporary, after a time the prothallus dies and the sporophyte grows into a massive leafy plant capable of self-support.

It is interesting to note that the embryological development of the sporophyte begins by a cell-wall cutting the egg-cell into two halves, one of which has the general character of stem, the other of a root. It is one of the many instances of the early differentiation of plant-embryos into what are known as a shoot-half and a root-half.

CHAPTER XI.

THE FLOWER OF THE BUTTERCUP (*Ranunculus*) AND OF THE BEAN (*Vicia faba*).

THE bean and the buttercup, whose flowers form the subject of the present chapter, belong to the important division of plants known as *Phanerogams*. They are separated from the class of plants known as *Cryptogams* (in which are placed Spirogyra, Mucor and the ferns) by certain well-marked characters connected with reproduction. Phanerogams are sometimes known as *Spermaphytes* or *Seed plants*, and this is a happily chosen name, for the production of *seeds* is the most characteristic feature of the class. The name *Flowering Plants*, which is a familiar equivalent for Phanerogam, is not so appropriate; while the term *Phanerogam*, implying that the process of reproduction is obvious or plainly visible, is particularly inappropriate. In reality the Cryptogams, whose title suggests obscurity in the matter of reproduction, have reproductive processes far more simple and more easily detected than those of the Phanerogams.

The bean and the buttercup both belong to a division of the Seed-plants characterised by the possession of two

cotyledons, and for that reason known as *Dicotyledons;* the tulip, on the other hand, which formed the subject of an earlier chapter, belongs to the *Monocotyledons,* or plants with a single cotyledon.

The Seed-plants are classified into a number of divisions known as *Natural Orders,* and the arrangement of flowering plants into these groups is an important part of the systematic botanist's work. The student of Elementary Biology is not expected to know this part of the subject, but he ought to have a rough idea of the general plan on which plants and animals are grouped. In collecting material for the study of the flower, the student will come across two kinds of buttercup, not identical in appearance, but both obviously buttercups. This relationship is technically expressed by saying that both plants belong to the *genus* Ranunculus, but that they are of different *species*:—for instance *Ranunculus acris* and *Ranunculus bulbosus.* Besides the genus Ranunculus there are other plants whose flowers are plainly built on the same general plan, for instance the Marsh Marigold (*Caltha palustris*) and the Globe Flower (*Trollius Europœus*). Other flowers such as the Columbine (*Aquilegia*) and the Larkspur (*Delphinium*) do not obviously resemble buttercups, but are found by analysis to be of the same structural type. All these genera, Ranunculus, Caltha, Trollius, Aquilegia, Delphinium and many others are massed together into the Natural Order *Ranunculaceæ,* so named after one of its constituent genera,—Ranunculus. In the same way the bean (*Vicia faba*), the pea (*Pisum*), the lupin (*Lupinus*), the clover (*Trifolium*) and scores of

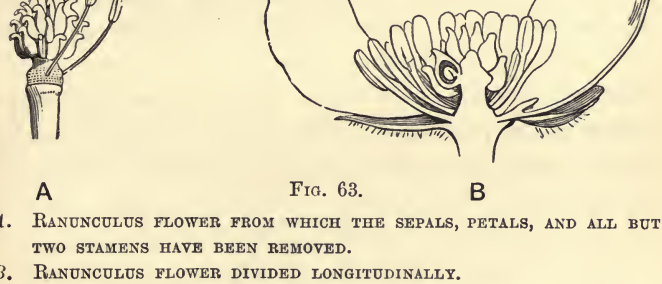
other genera constitute a Natural Order, the *Leguminosæ*.

In classifying, botanists are guided chiefly by the structure of the flowers,—by the form, number and position of the petals, and of the other floral organs, so that the morphology of the flower comes to be the key to the science of systematic or classificatory botany. And it should be noted that in classifying plants we are not simply satisfying the instinct which leads us to sort our possessions into like and unlike. The classification of living things has an interest which does not attach to the arrangement of artificial objects such as postage-stamps. Living things are not merely placed in groups as an expression of resemblance, they are classed in natural groups, that is to say they are ranged according to blood-relationship. Thus in the case of the Ranunculaceæ it is believed that all the genera are descended from a single ancient plant, and a wide field for speculation is open to us, as to how and why the primæval Ranunculus has left such varied descendants as the Larkspur, the Marsh Marigold, &c.

The flower.

The flower is essentially a shoot or axis bearing leaves on which the reproductive elements are produced. The proof that the petals and other floral organs are morphologically of the rank of leaves cannot here be given in any detail. A few of the arguments in favour of this belief may however be sketched. The development of the parts of the flower as superficial outgrowths from the growing

point is a leaf-like character; so is their arrangement in spirals or in circles (*whorls*) on the axis. Deformed or monstrous flowers supply interesting evidence: almost any part of the flower may abnormally take on an obviously leaf-like form. And in some cases the axis which bears petals below is prolonged beyond the flower and bears ordinary green leaves.



A FIG. 63. B

A. RANUNCULUS FLOWER FROM WHICH THE SEPALS, PETALS, AND ALL BUT TWO STAMENS HAVE BEEN REMOVED.

B. RANUNCULUS FLOWER DIVIDED LONGITUDINALLY.

(From Le Maout and Decaisne.)

The floral leaves are divided into two main groups. (1) Those which are essentially reproductive; and (2) those which are not essential to reproduction. Fig. 63 A shows a buttercup stripped of the non-essential parts and retaining part of the reproductive leaves grouped round the central axis. Fig. 63 B shows a longitudinally divided flower in which the non-essential parts of the flower are also shown. They consist of ten flattened leaf-like organs arranged in two groups of five each. In the horse-chestnut we had an instance of leaves springing from the stem opposite one another at the same level. In

the buttercup five floral leaves spring from the axis at practically the same level; and five others form a second group just above the first. In fig. 63 B two of the lower group[1] are visible, they are seen to be smaller than the leaves of the inner group (of which three are shown) and are also distinguishable by their hairy outer surface. This outer group is known as the *calyx*, and each of its constituent leaves is a *sepal*. The inner group of leaves is known as the *corolla*, and is made up of *petals*.

It is important to note that the petals are arranged alternately with the sepals: in other words the petals are not vertically above the sepals, but each petal springs from the floral axis on a line which if prolonged downwards would pass between the points of origin of two sepals. This arrangement will be understood from fig. 64,

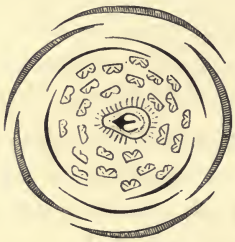


FIG. 64.

FLORAL DIAGRAM OF THE PEACH.

(From Le Maout and Decaisne.)

[1] In many flowers the floral leaves are spirally arranged on the axis, just as the foliage leaves are so disposed on the stem. This may be the case even when the floral leaves are obviously divided into groups, the members of which appear to spring from the axis all at one level. Such groups are conveniently called *whorls*, although this term strictly implies that the members are *not* spirally disposed.

which gives a *floral diagram*, or simplified bird's-eye view of a flower[1]; the two outer whorls are represented by brackets, the sepals being shaded, while the petals are black. In spite of the overlapping of the parts it is clear that the centre of any petal is half-way between the centres of two sepals. The importance of the alternation of petals and sepals will appear when the structure of the bean-flower is examined.

In the buttercup the petals are bright yellow, while the sepals are less bright in tint; in the bean the petals are black and white, while the calyx is nearly colourless. This is a general but by no means an absolute rule, namely that the calyx is green or dingy in colour, while the petals are conspicuous. It is also commonly the case that the sepals are of a simpler, less elaborate pattern than the petals: this is not obvious in the buttercup, where both are of a simple form; but in the bean the contrast is plain, the petals being of a specialised type, while the sepals are simple. A comparison of these flowers brings out another important point, namely that each sepal may be *free, i.e.* not united to the neighbouring sepals, as in the buttercup; or the sepals may be united into a cup or tube, as in the pea (fig. 67). Similar differences in regard to cohesion occur in the petals: thus in the cowslip they are united into a tube (fig. 65), while in the buttercup they are free. Other opportunities will occur of considering this point, which is here merely noted as one of the most

[1] The floral diagram, though not that of a Ranunculus, serves equally well to illustrate alternation.

striking characters in which the architecture of flowers is modified.

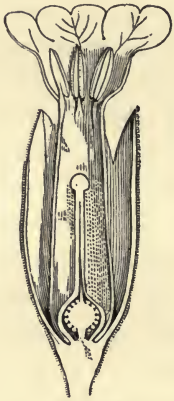


FIG. 65.
FLOWER OF THE COWSLIP DIVIDED LONGITUDINALLY.
From Le Maout and Decaisne.

Before passing to the reproductive parts of the flower a point in the structure of the buttercup petal must be noted,—a minute notched scale (fig. 66) at the base of the

FIG. 66.
PETAL OF RANUNCULUS,
showing the scale-like nectary at the base.
From Le Maout and Decaisne.

inner surface. This is known as a *nectary* and secretes the sugary juice called *nectar*, the importance of which in the natural history of the flower will be considered later.

Andrœcium and Gynœcium.

Above or within the petals the floral axis bears the parts of the flower which are essential to reproduction. The lower group of floral leaves is known collectively as the *andrœcium* because it is connected with the male or fertilising part of the process of reproduction. Above the andrœcium comes the *gynœcium*, where the egg-cell is found.

The andrœcium is made up of *stamens*, of which two only remain in fig. 63 A, the others having been removed; in fig. 63 B it may be seen that the stamens in the buttercup are numerous, the precise number being unimportant. Each stamen consists of a stalk—the *filament*, and a swollen elongated head—the *anther*. Within the anther are developed minute bodies—*pollen-grains*, by means of which the male element is conveyed to the egg-cell contained in the ovule. The pollen-grains are carried by the wind or by insects or other means to a part of the *gynœcium* where they germinate and by a long hypha-like tube transfer the male element to the egg-cell (for further details see Chapter XII). The pollen occurs in large quantities, and is familiar to most people as a floury, dusty material, frequently orange or yellow in colour, coating the ripe anthers. The pollen is developed in four cavities hollowed out in the anther: these *pollen sacs* are afterwards converted, by degeneration of two dividing walls, into two cavities. The fully developed anther opens or *dehisces* by two longitudinal fissures through which the pollen is set free. Above the stamens are the floral leaves known as *carpels*, constituting the gynœcium; and these,

like the members of the andrœcium, are arranged spirally on the axis of the flower. Each carpel may be considered a leaf folded so as to include a cavity. The hollow of the carpel is known as the *ovary* and contains an *ovule*. The ovule is simply a young seed; for our present purpose the only point of importance about the ovule is that in it is developed the *egg-cell* which afterwards gives origin to the embryo. In fig. 63 B one of the carpels is laid open so as to show the ovule within. At the hook-like upper end of the carpel is an organ called the *stigma*, whose function is to receive the pollen-grains and transmit, in a way to be described, the fertilising element to the egg-cell. The ovary and stigma[1] are the essential parts of the carpel, but usually there is a distinct stalk, the *style*, on which the stigma is borne; it is absent in the buttercup, but in the cowslip (fig. 65) the style runs up the centre of the flower as a delicate column, bearing a rounded stigma at its free extremity.

Bean-flower.

The structure of the bean-flower will be understood from the sketches of the very similar flower of the Sweet Pea (fig. 67). The flower stands with its axis more or less horizontal instead of approximately vertical as is the axis of the buttercup flower. It differs from the last named in the matter of symmetry; it is not uniformly symmetrical round its axis; this is clear when it is noted that the big petal marked *S* in fig. 67 has no counterpart on the opposite

[1] The term *pistil* is used to express the ovary, style, and stigma collectively.

side of the flower[1]. If however the flower is split into two by a median section in the plane of the paper, it will be

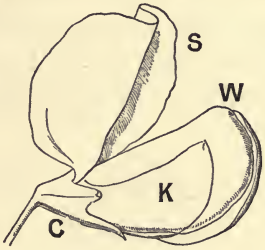


FIG. 67.

FLOWER OF THE SWEET PEA.

S, standard or vexillum. *W*, wings or alæ.
K, keel or carina. *C*, calyx.
(The flower had been preserved in alcohol, hence the keel was visible through the semi-transparent wings.)

divided into similar halves; it is in fact symmetrical about a median plane which, in the natural position of the flower, is a vertical plane.

The sepals, as mentioned above, are united into a tubular calyx the edge of which bears five teeth, and these indicate the number of coherent parts forming the calyx. When the calyx has been dissected off, the parts of the corolla are thoroughly exposed. The uppermost petal is the *standard* or *vexillum*, whose narrow horizontal base covers over the bases of the other petals, and whose broad apical part stands obliquely upwards. The name *standard* has been given to this petal because

[1] The flower of the bean, sweet pea, clover and other allied plants is said to be *papilionaceous* because its irregularity gives it a fancied resemblance to a butterfly.

it is raised like a flag, making the flower conspicuous. Next come two petals, the *wings* or *alæ*, standing symmetrically right and left of the median plane[1].

When the wings have been removed a hooded boat-like structure is seen which is called the *keel* or *carina*. The keel consists of two coherent petals, as is obvious

Fig. 68.

Floral diagram of a Papilionaceous flower.
From Le Maout and Decaisne.

when the floral diagram (fig. 68) of a pea-flower is examined. Within the five sepals (which are shaded) are shown—in black—the parts of the corolla; these are four in number, the lower one, representing the keel, being partly divided to indicate the union of two petals. The point of union of the two halves of the keel comes opposite the centre of the lower sepal; in other words this sepal *alternates* with the petals which make up the keel. In fig. 69, which gives a back view of the standard, it is seen that this is a single petal, since it falls between two sepals: the alternation of the standard may also be seen in the floral diagram.

[1] In the bean each wing is marked with a black spot. The wings require some slight force to detach them since they are superficially attached to the part of the corolla within, *i.e.* to the carina.

Within the keel are contained the andrœcium and the gynœcium. The stamens show a remarkable arrangement

FIG. 69.

FLOWER OF THE SWEET PEA.

S, the standard viewed from behind.
C, the calyx. *W*, one of the wings.

which is described by the technical term *diadelphous*. The horizontal bases of the filaments of nine of the stamens are united into a broad plate which, being longitudinally folded, makes a trough, while the tenth filament is free and roofs in the trough above. The nine stamens are not coherent throughout their entire lengths, their free apical parts bend upwards and terminate in anthers.

The gynœcium is contained in the trough of the united filaments; it consists of a single carpel, of which the horizontal part (in the trough) is the ovary, while the vertical part is the style which bears the stigma. The ovary of the pea differs from that of the buttercup in containing several ovules, as may be seen in fig. 70, where however only part are shown. The cavity of the ovary is made by the folding of the carpellary leaf, and the ovules

are borne along the leaf's united edges. The ovary finally developes into the *pod* and the ovules into peas,

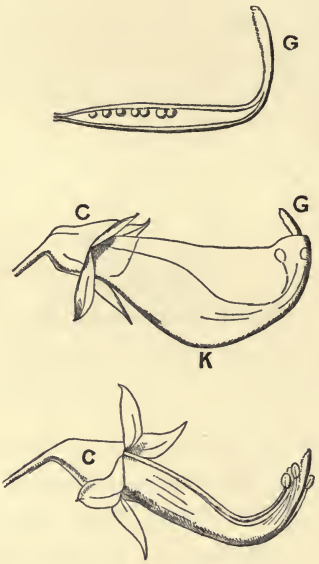


Fig. 70.

Flower of the Sweet Pea.

In the central figure is seen the keel (*K*), through the walls of which can be seen the swelling ovary and some of the stamens. The style *G* projects from the apex of the keel. *C*, the calyx.

The lower figure gives the 9 united filaments, the 10th or free stamen, and the projecting style.

The upper figure gives the horizontal ovary containing ovules, and the vertical style *G*.

when it is a familiar fact that the peas are attached along one edge partly on the right and partly on the left-hand valve of the pod,

Fertilisation by means of insects.

In order that the egg-cell may be fertilised it is necessary that pollen shall reach the stigma. The question therefore how the pollen reaches this position has to be met, and the flowers of the papilionaceous type are well adapted to illustrate one of the chief means of pollen-distribution, namely by means of the visits of insects. When it is understood that it is advantageous to the species that its flowers should be so visited, we can understand the meaning of many parts of the flower which without the knowledge of this fact would be meaningless. Thus the bright colours and sweet scents of flowers undoubtedly serve to attract insects, while the sugary juice or nectar supplies a more substantial attraction. In the buttercup the scale-like nectary has been described; in the pea-flower the receptacle is more elaborate, being in fact the trough made by the united filaments. The freedom of the tenth stamen gives the visiting insect access to the nectar, and that this is the meaning of the arrangement is clear from the fact that where (as in the Broom) there is no nectar (the flower being visited by bees for the sake of the pollen), the tenth stamen is united to its nine fellows[1].

The flowers of the bean and pea are especially adapted to be fertilised by bees, and the manner in which these insects visit them presents some points of interest. In settling on the flower the bee uses the alæ as a stage to alight on, and these petals being intimately in connection

[1] The stamens are then said to be *monadelphous*.

with the keel, the weight of the insect is brought to bear on the keel and forces it downwards so that the anthers and the style emerge and touch the under side of the bee's body. The union of the wings and keel is effected in the pea-flower by an interlocking of protuberances and depressions which can hardly be understood without examining the flower. In the bean the adhesion of the wings to the keel has a similar use. The bee not only carries away pollen from the flower visited, but also brings to it pollen which had adhered to its hairy coat during previous visits. In this way the insect will smear the stigma with pollen and at the same time carry off a fresh supply for future fertilisations. When the bee, after having sucked the nectar, flies away, the keel, relieved from its weight, springs up into its former position and once more covers up the andrœcium and gynœcium in its hood. In a wet climate like that of England this arrangement must be of service to the plant in protecting the anthers from wet,—for it is a matter of experience that pollen is injured by rain: the nectar too is thoroughly sheltered and cannot be diluted or washed away by a shower.

In books[1] especially devoted to this subject many other details are given as to the adaptation of papilionaceous flowers to the visits of insects. What is here given must suffice for our present purpose.

[1] See *The Fertilisation of Flowers*, by H. Müller, 1883.

CHAPTER XII.

DISTRIBUTION OF POLLEN BY THE WIND AND BY INSECTS —SELF AND CROSS FERTILISATION—DICHOGAMY—PLANTAGO—SILENE—DOG-DAISY OR CHRYSANTHEMUM LEUCANTHEMUM.

Of the flowers which form the subject of the present chapter, two, namely Silene and the dog-daisy (Chrysanthemum), are visited by insects, and the distribution of the pollen is carried on by their agency. In the remaining flower, the plantain (*Plantago lanceolata*), the pollen is carried by the wind. A number of other plants are in the same case, for instance fir trees, the yew, hazel, oak and the great class of grasses: such plants have certain characters in common, which may be demonstrated on the plantain. The "heads" of the plantain are made up of a number of minute flowers massed together, each flower consisting of four simple sepals, and a tubular corolla of four membranous brown petals.

Here we have one of the chief characteristics of wind-fertilised plants, namely that the flowers are small, simple, and inconspicuous, presenting a striking contrast to the brightly coloured petals of insect-fertilised flowers. The

plantain has no scent, and does not secrete nectar; in fact it has none of the qualities which were referred to above as serving to attract insects[1].

Another point is the production of great quantities of pollen; this is not so striking in the plantain as in some other members of the wind-fertilised class, for instance in the yew or pine, in which the clouds of dusty pollen, which may be shaken out of a branch, are familiar to every one. In this way pollen comes to be widely distributed, and has been found in the dust collected at considerable heights in the air.

The biological meaning of this profusion of pollen is clear enough: the plant has to trust to chance for the conveyance of pollen from stamen to stigma, instead of to the visits of insects by which small loads of pollen are transferred directly from flower to flower. Thus to make sure of all the countless stigmas on an oak tree being dusted with pollen, enormous and apparently wasteful quantities of the material must be manufactured. The pollen-grains of wind-fertilised plants are smooth, dry and incoherent, and seem especially adapted for floating like dust in the air.

On the other hand the pollen of insect-fertilised plants is coherent like a damp powder. This quality is generally due to the coats of the pollen-grains being sculptured into minute prickles so that the grains cohere in groups and masses; the dog-daisy supplies an instance of rough-coated pollen-grains.

[1] Some species of Plantago are visited by pollen-collecting insects, and are both scented and conspicuous in colour.

In the plantain the filaments of the stamens are enormously long in proportion to the size of the flower; this is frequently the case in wind-fertilised plants, for instance in the wheat-flower shown in fig. 71.

FIG. 71.

WHEAT-FLOWER,

showing the large anthers hanging far out on long flexible filaments. Above are the two large branching styles. *sq*, the scaly floral leaves. From Le Maout and Decaisne.

In consequence of this character the anthers are well exposed and easily shaken by the wind, and the distribution of the pollen correspondingly favoured. In the "catkin" of the hazel the same end is brought about by other means. The catkin is an *inflorescence*,—a stalk bearing numerous minute flowers, the stamens are short, but the whole inflorescence is pendant and flexible, and easily shaken by the wind. In the nettle the filaments are at first bent inwards towards the centre of the flower, but later on they uncurl with a sudden movement, scattering

their pollen in a minute explosion. The same thing is seen in the "artillery plant" (Pilea) which is sometimes grown in green-houses, and receives its name from the puff of smoke-like pollen given out from its exploding stamens.

Wind-fertilised plants also show a certain resemblance to one another in the character of the gynœcium. Since the stigma receives the pollen fortuitously, the chance of fertilisation is increased when the stigma is large. The stigmatic surface in the plantain is great in proportion to the size of the flower, and the same thing is particularly striking in the wheat-flower figured above (fig. 71). This is a general character of the class of flowers we are considering, though the extension of surface is brought out in different ways, for instance in the walnut the stigma is a broad plate-like structure, instead of being papillated or divided, as in the plantain and the grass.

Self- and cross-fertilisation.

When a flower is fertilised by pollen from its own anthers or from the anthers of a flower *on the same plant*, the process is called *self-fertilisation*. When the pollen comes from a distinct individual, it is known as *cross-fertilisation*. Some species of plants, for instance the nettle, are divided into two classes of individuals: (1) consisting of plants whose flowers have stamens but no carpels; (2) of plants whose flowers have carpels but no stamens. Reproduction must in this case (if it occurs at all) be the result of cross-fertilisation. But in the flowers whose structure we have been considering it is obvious

that either cross- or self-fertilisation *may* occur. There are however a variety of characters found in flowers which are apparently adapted to favour cross-fertilisation, that is to render it more probable that the plant shall be cross- than self-fertilised.

Experiment has shown that the offspring of cross-fertilisation is more vigorous than that of self-fertilised flowers, so that any adaptation which favours cross-fertilisation is an advantage to the species. These experiments make it possible to understand why so many flowers present arrangements by which cross-fertilisation is favoured. Such modifications will be preserved in the struggle for existence because they increase the general effectiveness of the species.

Dichogamy.

In the nettle, as above mentioned, cross-fertilisation is a necessity, because the pollen-grain and the egg-cell are the product of different individuals. The gynœcium is separated *in space* from the andrœcium. In the phenomenon known as *dichogamy* the separation is one of time, not of space.

The plantain is a good example of this state of things. The head or inflorescence of the plantain bears a series of flowers of graduated ages, those at the base are the oldest, while the free end of the spike bears the youngest flowers. The younger flowers (fig. 72 *Y*) show a stigma projecting beyond the corolla, but no stamens are to be seen. On dissection they will be found in an immature condition, tucked away within the flower. In this stage the flower

does not, as far as fertilisation is concerned, differ from a flower devoid of stamens. If it is fertilised the pollen

Fig. 72.

Protogynous flower of Plantago lanceolata.

Fig. *Y*, in the younger stage with the style *S* projecting. Fig. *O*, in the older stage with full-grown stamens (*A*) and withered style (*S*). From Müller's *Fertilisation of Flowers*.

must come from another flower; it may of course be pollinated by a flower on the same inflorescence with itself, but at any rate its chance of cross-fertilisation is increased, since the pollen *may* come from another plant. As the flower gets older the stigma withers, it no longer has the fresh velvety look of a receptive stigma (*i.e.* one capable of pollination), and it does in fact cease to function. But the flower as a whole has not ceased to function, for as the stigma withers the stamens develope and the older stage, shown in fig. 72 *O*, comes on, in which it produces pollen, not for its own fertilisation, but for

that of another flower. The particular form of dichogamy in the plantain is known as *protogyny*[1] because the gynœcium matures before the andrœcium. When the reverse is the case, as in Silene and in the dog-daisy, the term *protandry* is used, and the flowers are called *protandrous*.

Silene.

In fig. 73 the partly dissected flower of a species of Silene is shown. The calyx has been removed with the exception of two torn strips at the base.

In an undissected flower it is seen to be a deep tubular cup made of five united sepals. The rest of the flower is raised on a stalk (visible in the figure below the ovary *G*) as though an internode were interpolated between the calyx and the rest of the floral leaves. The petals are five in number and are free from each other,—that is to say they do not cohere into a tube. Each petal has a tall thin vertical stalk, the *claw*, and a broad horizontal *lamina* or *limb*; it is the limbs of the petals which make up the conspicuous disc-like face of the flower.

Within the petals are the ten stamens, of which seven only remain in fig. 73; they will be found to be sticky with nectar, or indeed dripping with the sweet fluid excreted by glandular nectaries inside their bases. The gynœcium (*G*, fig. 73) is the first instance which we have met with of the coherence of more than one carpellary leaf to form a single ovary. Here there are three

[1] The flower is said to be *protogynous*.

such leaves so fitted together that the resulting ovary is divided into three compartments; this may be seen in a

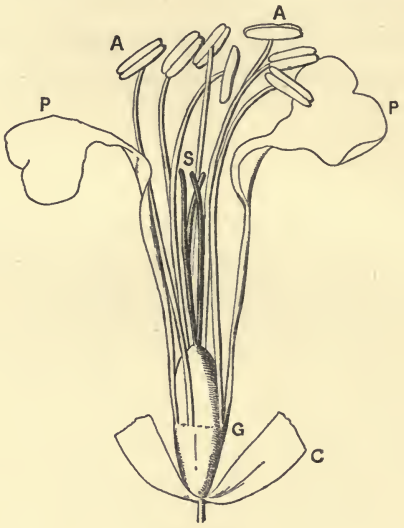


FIG. 73.

YOUNG FLOWER OF A SILENE, PARTIALLY DISSECTED.

C, one of two remaining fragments of the calyx.
G, the internode (*anthophore*) which is surmounted by the ovary, and bears the petals and stamens.
P, *P*, the two remaining petals.
A, *A*, anthers; three of the stamens have been removed.
S, the immature styles.

transverse section of the ovary, which will also show the ovules springing from the point of union of the three component carpels. The existence of three carpels is indicated, not only by the three compartments of the ovary, but also by the three styles which surmount it.

In the young flowers (fig. 73) the styles are seen to be

only half grown while the anthers (*A*) are mature and project from the mouth of the corolla; in the older flowers the anthers having played their part wither and fall from the filaments, while the styles, having become mature and capable of pollination, have grown so that they project at the mouth of the corolla and occupy the position of the stamens in the younger flower.

Dog-daisy (*Chrysanthemum leucanthemum*).

What is ordinarily called the flower of the daisy is in reality an inflorescence,—a number of minute flowers massed together on a button-shaped stalk[1]. The white rays springing from the edge are not petals, as they are so often called, but each is a minute flower or *floret*, and the same thing is true of the minute round-headed pegs which make up the yellow mosaic-work in the centre of the flower-head. We have in fact a state of things essentially the same as that in the plantain, the shape of the axis on which the florets grow being the only point of difference between the two forms of inflorescence. In the dog-daisy the flower-head is surrounded by a number of green scales (*bracts*) which help the deceptive likeness of the head to a flower, by resembling a calyx.

In the daisy the yellow florets which make up the centre of the head are known as *disc-florets*; each has a minute tubular corolla edged with five small teeth indicating the five coherent petals. A floret of this kind from a Senecio (a species allied to the common groundsel) is shown in fig. 74, *A*. In fig. 74, *C* is shown a floret in

[1] The expanded axis on which the florets grow is called the *receptacle*.

which the tube of the corolla is open down one side so that it ends in a flat expansion, from which it takes the name of a *ligulate* or strap-like floret. The white florets of the Chrysanthemum, which are known as *ray-florets*, are of the type shown in fig. 74, *C*, but the ligulate part is proportionately much longer than in Senecio. Not only do the disc and ray florets of the dog-daisy differ from

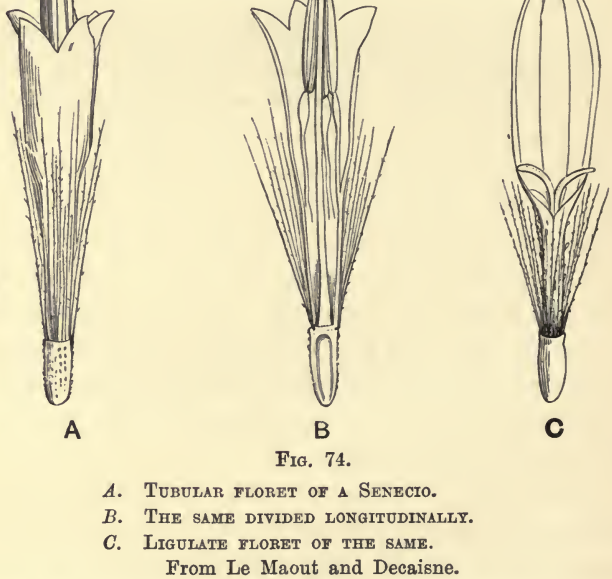


FIG. 74.

A. TUBULAR FLORET OF A SENECIO.
B. THE SAME DIVIDED LONGITUDINALLY.
C. LIGULATE FLORET OF THE SAME.
From Le Maout and Decaisne.

each other in form and in colour, but in their reproductive organs. The ray-florets have an ovary, a style and a stigma, but no anthers, while the disc-florets possess both andrœcium and gynœcium. In some allied plants the

differentiation is carried a step further,—the outer florets lose the gynœcium and become sterile or sexless: this is the case with the blue corn-flower (Centaurea). In the dog-daisy the florets have no calyx, but in most plants of the natural order *Compositæ*[1] the calyx is present although greatly metamorphosed. In fig. 74, *B* fine radiating hairs are seen springing from the base of the corolla: these make up what is known as the *pappus*, which is in reality the metamorphosed calyx. A simpler pappus is seen in fig. 75.

In figs. 74, 75 it is plain that a structure of some kind projects below the point of origin of the calyx and corolla; this is the ovary,—which in fig. 75 is laid open so as to show the solitary ovule contained within its cavity. It is a striking morphological character of the florets that the ovary is below the point whence spring the calyx and corolla, instead of being, as in the buttercup, above that point. The ovary of the dog-daisy is said to be *inferior*, that of the buttercup *superior*: in the following chapter it will be shown that intermediate cases connect these types of floral structure.

The stamens[2] are five in number and instead of springing from the axis of the flower they arise from the internal surface of the corolla, as may be seen in fig. 74, *B* and in fig. 75. A similar state of things may be seen in the cowslip flower given in fig. 65, p. 146. The characteristic

[1] The natural order Compositæ comprises the sunflower, dandelion, groundsel, dog-daisy and many other common flowers.

[2] For the structure and arrangement of the stamens it is well to dissect a floret of one of the garden Centaureas.

feature of the androecium is the coherence of the anthers into a hollow cylinder[1] while the filaments are free. It is

Fig. 75.

Flower of Centaurea divided longitudinally.
From Le Maout and Decaisne.

a state of things the reverse of what is seen in the bean-flower, where the filaments of nine of the stamens are coherent while the anthers are free.

The pollen of the daisy is shed, and collects inside the tube made by the united anthers. The anthers ripen and

[1] When this is the case the anthers are called *syngenesious*.

discharge themselves (as in Silene) before the stigma is ready for pollination, so that while the pollen is being discharged the style is hidden within the anther tube. The two branches of the bifid extremity of the style have not yet opened out into the *Y* like form shown in fig. 74, which would indeed be impossible within the anther tube. The branches of the style are closely appressed to each other; they point vertically upwards and bear at their upper ends a tuft of short hairs (faintly visible in fig. 74 *A*). The lower part of the style begins to grow in length, so that the pollen is gradually pushed or swept out at the mouth of the anther tube by means of the brushes at the free ends. All this time fertilisation is impossible, in spite of the fact that the end of the style is covered with pollen, because the stigmas are still unripe, and incapable of pollination. As the pollen is pushed out it is carried away by insect visitors and part of it appears adhering to the style, when by continued growth it emerges from the anther tube. The stigmas become receptive and the branches of the style open out as shown in fig. 74. All the various stages of this process may be studied in the flower-head of the dog-daisy. In the centre of the disc are the youngest florets still unopened, further towards the circumference are florets, the anther tubes of which are crowned with emerging pollen, and further still from the centre are seen the extruded styles with widely opened branches.

CHAPTER XIII.

MORPHOLOGY OF THE INFERIOR OVARY—THE CHERRY—THE GOOSEBERRY—THE OVULE—THE EGG CELL—THE POLLEN GRAIN AND FERTILISATION—EMBRYOLOGY.

THE present chapter deals principally with the structure of the ovule, and the development of the embryo from the egg-cell. It also serves as an introduction to Ch. XIV. in which the fruit is considered in detail; for this reason the morphology of the ovary is illustrated by two examples,—namely the cherry (or peach) and the gooseberry.

Cherry or Peach.

If the flower of either of these species is divided longitudinally as shown in figs. 76, 77, it will be seen that the stamens, petals and sepals arise close together from the edge of a cup, in the bottom of which the ovary is seated. We might imagine a flower of this type to be evolved from a flower like that of the buttercup by the fusing together of the basal parts of the calyx, corolla and

of the filaments of the stamens. The cup which contains the ovary would be formed of these adherent parts

FIG. 76.

FLOWER OF THE PEACH,
divided longitudinally.
From Le Maout and Decaisne.

and the edge of the cup would simply be the place where the various whorls of the flower were no longer adherent.

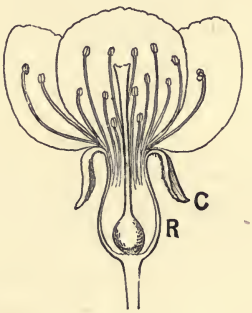


FIG. 77.

CHERRY FLOWER,
longitudinally divided.
R, the hollow receptacle. *C*, the calyx.

This, however, would not be the correct way of describing the architecture of the flower.

In reality the cup is the axis or receptacle of the flower which assumes this remarkable form. The hollowing out of the receptacle brings the points of origin of the calyx, petals and stamens above the ovary, reminding the observer of the state of things in the florets of the dog-daisy. If the edges of the cup in figs. 76, 77 were brought together, the ovary would be contained in a closed cavity instead of an open cup, and the calyx, corolla and stamens would spring from the roof of the cavity. We should then have a flower like that of the Madder shown in fig. 78, which only differs from our imaginary

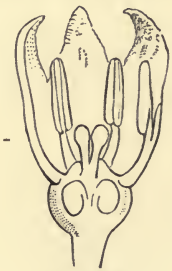


FIG. 78.

FLOWER OF MADDER (*Rubia tinctorum*),
divided longitudinally to illustrate an inferior ovary.
From Le Maout and Decaisne.

case in this:—that the space between the ovary and the enclosing walls of the closed cup has disappeared, or in other words the walls of the hollowed-out receptacle have coalesced with the walls of the ovary. What is here described as an imaginary case is believed to have really

taken place in the evolution of the inferior ovary, of which the gooseberry supplies an example. Fig. 79 shows the

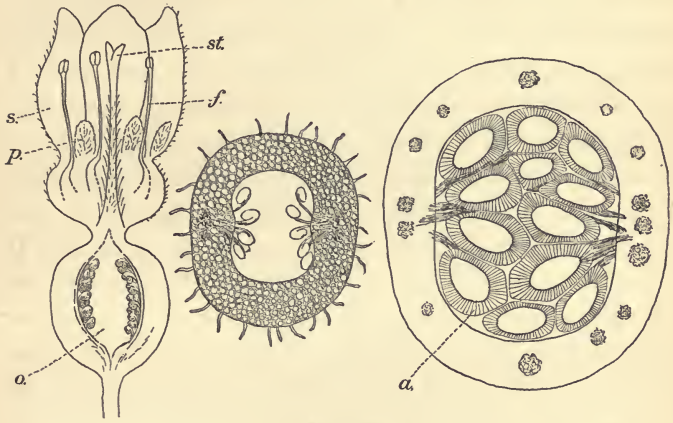


FIG. 79.

GOOSEBERRY.

On the left, the flower longitudinally divided.

o, the cavity of the ovary; *p*, petals; *s*, sepals; *f*, filaments; *st*, the bifid stigma.

In the centre, a transverse section of the ovary.

On the right, a transverse section of the ripening fruit.

a, transparent cells of the testa (see Ch. XIV.).

inferior ovary surmounted by the rest of the flower, of which the most characteristic feature is given by the five minute petals alternating, on one hand, with the five calyx-lobes, and on the other with the five stamens. The ovary is made up of two carpels as is indicated by the bifid stigma, and by the two opposite *placentas* or regions which bear the ovules: this is especially well seen in the transverse section of the ovary[1].

[1] The fruit is described in the following chapter.

Ovule.

The structure of the ovule may be studied in the marsh-marigold (*Caltha palustris*), a plant which has already been utilised for the study of the anther. Caltha belongs to the Ranunculaceæ, and like the buttercup it has a group of free carpels in the centre of the flower. Each carpel resembles a miniature pea-pod, and contains several ovules borne on the united edges of the carpellary leaf. The ovule or immature seed is attached to the carpel by a stalk known as the *funicle*, by which food is supplied to it from the mother plant. The scar left at the point of attachment of the funicle to the seed has already been described, under the name of the *hilum* in Chapter II. The ovule consists of a mass of simple cellular tissue, the *nucellus*, *n* in fig. 80, within which is contained the egg-cell. The nucellus is covered by an integument, *i*, which on the left side of the nucellus (away from the funicle) is seen to be made up of two layers. The integuments do not completely shut in the nucellus, a narrow gap is left at *m* leading from the cavity of the ovary down to the nucellus. This passage is the micropyle which persists in the adult seed as a hole in the seed-coats (see the drawing of the seed of *Vicia faba*, fig. 4, p. 17). In the ovule its function is to admit the pollen-tube by which fertilisation is effected. If a line is drawn along the funicle as far as the base of the ovule, and then through the longer axis of the ovule to the micropyle, the result will be a curved line ∩ like the letter U reversed. When this is the case, so that the micropyle is close to the point of origin of the funicle, the ovule is described as

anatropous. The biological meaning of the inversion of the ovule is not clear, but, like many other characters of

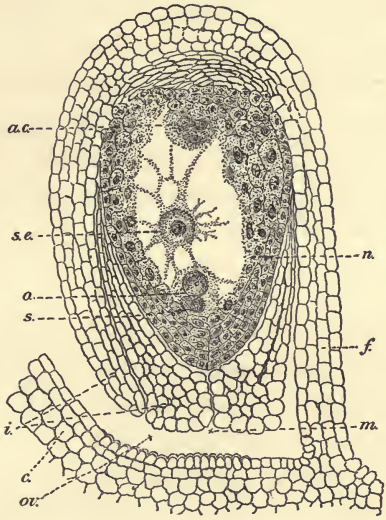


FIG. 80.

LONGITUDINAL SECTION THROUGH OVULE OF CALTHA.

c, wall of ovary. *ov*, cavity of ovary. *f*, funicle.
i, integuments of ovule. *m*, micropyle. *n*, nucellus.
s.e, secondary nucleus of embryo-sac. *o*, egg-cell.
s, one of the synergidæ. *a.c*, antipodal cells.

unknown physiological importance, it is a distinction of value to the systematic botanist. Thus certain groups of plants are characterised by possessing an anatropous ovule, others by the presence of an *orthotropous* ovule, *i.e.* one in which the funicle and the axis of the ovule are in a straight line.

The embryo-sac and egg-cell.

In a young ovule—younger than that sketched in fig. 80—a single cell can be detected as differing in size and appearance from its neighbours: this cell is called the *embryo-sac.* The embryo is developed in its cavity, which ultimately developes into a large hollow in the substance of the nucellus. In fig. 80 the embryo-sac is shown as a white space in the middle of the dark nucellus. The embryo in fig. 82 lies in the embryo-sac, the limits of which, however, are not shown.

The nucleus of the embryo-sac undergoes a certain process of division which leads to the state of things shown in fig. 80, where a *secondary nucleus* has arisen, together with certain other structures of even greater importance. The primary nucleus divides into two halves, and these halves again divide so that there come to be four nuclei at one end of the embryo-sac, and four at its other extremity. Two of the nuclei, viz. one from each group of four, travel to the middle of the embryo-sac and there unite to form the *secondary nucleus* of the embryo-sac. One of the three nuclei remaining at the micropylar end of the embryo-sac becomes the nucleus of the *egg-cell,* while the other two form what are known as the *synergidæ.* The three nuclei at the opposite end of the embryo-sac form a group known as the *antipodal cells.* The last-named cells are of no further importance, the interest now centres in the egg-cell, and in a much less degree in the synergidæ.

To make the further history of the egg-cell clear, it is necessary to return to the pollen-grain. The germination

of pollen may be watched by cultivating the grains in sugar solution, or the pollen may be made to germinate in a natural manner on the stigma, which must then be examined in longitudinal sections. A section of this sort is diagrammatically represented in fig. 81. The pollen-

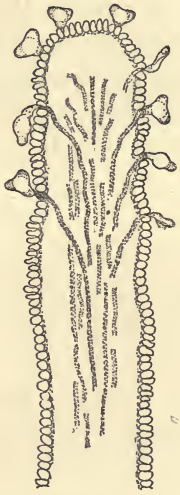


FIG. 81.

DIAGRAMMATIC SKETCH OF POLLEN GRAINS, germinating on the stigma of Œnothera, the Evening Primrose. The tissue in the interior of the section is not shown.

grains of the Evening Primrose are triangular in outline, and the angles are the places whence, in the process of germination, the hypha-like pollen-tubes grow forth. It passes between the superficial cells of the stigma and burrows like a fungus in the tissues of the style. It feeds, as it grows, on the tissues through which it passes, so that it not merely resembles a fungus hypha in appearance, but also behaves like one, being in fact, for the time being,

a parasitic growth. In this way the pollen-tube travels down the style, emerges into the cavity of the ovary, and finally grows down the micropyle. By this time the tissue of the nucellus has been so much encroached on by the growth of the embryo-sac that the pollen-tube at the inner end of the micropyle is close to the egg-cell. The act of fertilisation,—the transference of something from the pollen-grain to the egg-cell is not yet completed, but it at last seems to be a possibility.

The pollen-grain although it looks like a single cell is in reality a compound structure. By appropriate treatment two nuclei are revealed within the pollen-grain, indicating the presence of two cells, which however in the majority of the Phanerogams are not separated from each other by cell-walls. Of the two nucleated protoplasts contained within the wall of the pollen-grain, one is called the *generative*, the other the *vegetative* cell. The functions of these cells are indicated by their names, the generative cell is essentially the reproductive part of the grain, while it is the vegetative cell which germinates and produces the pollen-tube. The generative nucleus divides into two nuclei which travel down the pollen-tube and finally escape, through the wall of the tube, into the embryo-sac. One nucleus usually fuses with the *secondary nucleus* of the embryo-sac (a process with which we are not further concerned) while the other nucleus unites with the egg-cell and fertilises it.

Embryo.

The development of the embryo from the egg-cell may be studied in the Shepherd's Purse (*Capsella bursa-*

pastoris) in the manner described in the *Practical Work*, No. XIII.

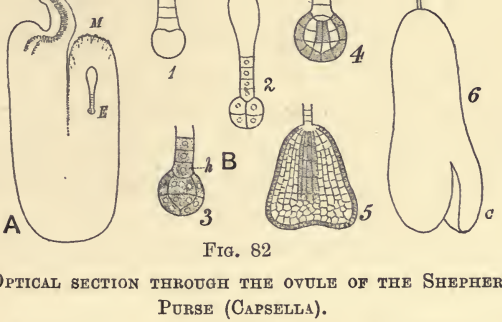


FIG. 82

A. OPTICAL SECTION THROUGH THE OVULE OF THE SHEPHERD'S PURSE (CAPSELLA).

F, funicle; *M*, micropyle; *E*, embryo.

B. STAGES IN THE DEVELOPMENT OF THE EMBRYO.

1, suspensor, bearing below the undivided embryo-cell.

2, embryo (*i.e.* excluding the stalk or suspensor) consists of eight cells.

3, the primary epidermis has appeared: *h* is the hypophysis, *i.e.* the last cell of the suspensor.

4, the primary vascular cylinder (shaded) has appeared: the hypophysis has divided, part goes to make part of the embryo.

5, 6, older stages: 6, with well-formed cotyledons (*C*).

The first stage (which is not shown in fig. 82) is the division of the egg-cell into two parts; one, which may be called the upper cell, being next to the micropyle end, while the lower cell points to the cavity of the embryo-sac. The latter, which is called the *embryo-cell*, gives rise by cell-division to nearly the whole of the embryo; the upper half gives rise to a simple row of cells called the *suspensor*, because, by it, the main body of the embryo is hung as by a stalk. The minute swollen head at *E* in fig. 82, A, is the very young embryo and the stalk, by which it hangs from the micropylar end of the embryo-sac, is the suspensor.

The next stage of interest is shown in fig. 82, B 2, where the embryo-cell at the lower end of the *suspensor* has divided into eight cells, of which, however, only four are visible. Of these eight cells, the four lower ones, *i.e.* the four which make up the free rounded end of the embryo, give rise to the cotyledons and plumule, while the four next the suspensor give rise to the radicle. Thus when the embryo consists of no more than eight cells, it is possible to distinguish in it distinct morphological regions.

In fig. 82, B 3, it will be seen that the lowest cell of the suspensor *h* projects slightly into the spherical body of the embryo. This projecting cell is called the *hypophysis*, and its encroachment among the cells of the embryo indicates its further history: for the hypophysis takes a share in the architecture of the embryo, by dividing and supplying a group of cells at the upper end of the embryo. Thus the embryo-cell gives rise to plumule, cotyledons and part of the radicle, while the hypophysis gives rise to the tip of the root and the root-cap. In fig. 82, B, it may be seen how the eight cells[1], of which the embryo consists in B 2, have produced curved superficial cells in B 3: these are the *primary epidermic*, or as they are called, the *dermatogen* cells. The eight dermatogen cells give rise by continued division to the superficial cells over the whole of the plant, except in the region of the root built up by the hypophysis. This is a good instance of a "tissue by birth right[2]," the epidermis comes to be one of the fundamental divisions of plant-tissues because it originates thus early in the history of the embryo.

[1] Only four being visible. [2] See p. 37.

In fig. 82, B 4, a central core of tissue is beginning to be marked out in the centre of the embryo, as indicated by shading; this core, which is seen increasing in fig. B 5, is the beginning of the vascular cylinder, which in the embryonic condition is known as the *plerome*. These two points—the early appearance of the primary epidermis, and the early appearance of the vascular cylinder—are the most important features in the histology of the embryo.

The growth of the embryo is provided for by a supply of reserve material, stored up in a specially developed mass of cellular tissue which forms inside the embryo-sac. This, which is known as *endosperm*, is the product of the secondary nucleus (*s.e.* fig. 80) of the embryo-sac. In some cases, *e.g.* in grasses, the endosperm is formed in such quantities that it is not all used in the growth of the embryo; thus in the mature seed the embryo is accompanied by a mass of endosperm, which is not utilised until, on the germination of the seed, the embryo begins to grow. In the seeds which have been studied in earlier chapters, namely those of the bean, the gourd and the sunflower, the mature seed contains no endosperm. There the endosperm has a temporary importance, supplying food to the embryo as it grows: by the time the cotyledons have reached their full size, the endosperm has disappeared, and the whole cavity of the seed is occupied by the embryo. What occurs on germination, when the embryo wakes from its resting stage, has already been described in Chapter II.

CHAPTER XIV.

THE FRUIT—DISTRIBUTION OF SEEDS BY WIND—BY ANIMALS—WINGED SEEDS AND FRUITS—BURRS—EDIBLE FRUITS.

In the last chapter the development of the seed has been traced, and in one of the earlier chapters the germination of seeds has been described. But there is a gap in the natural history of the plant between the ripe seed contained in the ovary of the mother plant, and the seed germinating in the earth. It is the object of the present chapter to fill up this gap, by giving an account of the methods by which seeds are sown in nature; while the examples on which these methods are studied will also illustrate the morphology of the fruit.

When it is considered that a plant is a stationary object, it is obvious that the seeds must be in some way or other supplied with the means of locomotion, otherwise it would be impossible that the seedlings should hit on suitable habitats. The means by which pollen travels have been described, and the *distribution of seeds* is an equally important section of the natural history of plants.

The fact that seeds are widely scattered is proved by the plants which grow on the walls of ruined buildings, or in the mould accumulating in the tops of pollard trees, where the seeds had certainly not been sown by man. So numerous are the plants growing in such places that *Floras, i.e.* lists of the vegetation, have been compiled for Cologne Cathedral (in its unfinished condition), the Colosseum at Rome, for certain church towers in France, and for the pollard willows near Cambridge.

The chief means by which seeds are scattered, are the following:

I. They may be blown by the wind.

II. They may be carried in the form of *burrs* adhering to the hair of animals.

III. They may be swallowed by animals, and may germinate after passing through their bodies.

I. *Wind-Distribution.*

The spores of Mucor and those of the fern supply instances of reproductive units whose distribution is facilitated by minuteness. The seeds of flowering plants are not generally so small as to approximate to the dust-like character of spores, but the seeds of some Orchids are exceedingly minute and are doubtless far more readily wafted by currents in the air than is possible in the case of more massive seeds. The more common adaptation to aerial carriage is a specialisation in the matter of form. Many seeds have a thin membranous border which increases their area without perceptibly increasing their weight, so that when freed from the mother plant they

fall slowly through the air and may readily be carried to some distance from the parent. A seed of this sort is given in fig. 83.

Fig. 83.

Seed of Bignonia albo-lutea,
showing the expanded membranous edge or wing. Life size.

The fall of these seeds is beautiful to see; they swoop and shift with a zig-zag flight, like a rook or peewit "tumbling" in the air, or like a slate falling through water.

In some cases seeds which are not flattened, or winged with membranous borders, are distributed by an arrangement called the "censer mechanism." This may be seen in the Larkspur (Delphinium): the minute shining seeds are found, when ripe, lying loose at the bottom of the pod-like seed-capsules. They cannot fall out because the capsule is closed except for a cleft near the top, but can be jerked out by anything that shakes the plant,—probably the wind or a passing animal would serve the purpose in a state of nature. The poppy scatters its seeds by the same mechanism, the seed-capsule being pierced by a ring of small holes just below the radiating stigmas which crown the capsule. In these and similar cases the fact that the seeds are not easily thrown out of

the seed-vessel prolongs the process of distribution: the seeds are not all scattered at once, and are therefore probably cast in a number of different directions.

In all these cases the ovary which serves as the "censer," from which the seeds are swung forth, remains on the plant, but in many plants the ovary adheres to the seed and is cast off with it, from the parent plant. When this is the case the *fruit* (*i.e.* the ovary together with its contained seeds) is, in common language, described as a seed; thus a grain of wheat or barley is generally considered to be a seed, whereas it is in reality a fruit containing a single seed. In the same way, what is commonly called the seed of a sunflower is in reality the inferior ovary in which the seed is hidden. The same is true of the dandelion "seed" (fruit)[1] shown in fig. 84.

FIG. 84.

FRUIT OF DANDELION.

From Le Maout and Decaisne.

[1] In botanical language the word *fruit* does not imply that the object described is eatable.

The corolla has fallen off and the *pappus* or hair-like calyx has developed into a delicate crown separated from the ovary by a stalk. The crown of hairs serves as a parachute which buoys up the fruit and enables it to float on the wind to great distances.

The fruits of the Ash (*Fraxinus*) and of the Sycamore (*Acer pseudoplatanus*) are also wind-distributed, although not so effectively as the "clocks" of the dandelion.

The fruits or "keys" of the ash are familiar to everyone, and are seen in the summer and autumn growing in

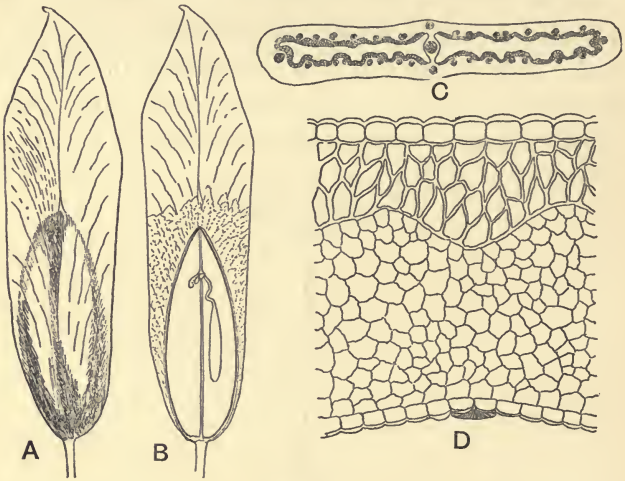


FIG. 85.

A. FRUIT OF THE ASH.

B. THE SAME OPENED, showing a single ovule developing into the seed while the remaining three ovules do not develop further.

C. TRANSVERSE SECTION OF THE LOWER PART OF *A*, showing the cavity of the ovary, and the vascular bundles of the two carpels.

D. A SMALL PART OF *C*, more highly magnified, showing the thick-walled cells next the inner surface.

large green bunches on the tree. Each key is shaped something like the head of a lance, and consists of a thicker basal part, the cavity of the ovary, and a thinner apical part which serves as a wing, that is to say it serves, like the winged border of the seed sketched in fig. 83, to increase the area of the fruit, and make it fall slowly through the air. It is certainly not a perfect flying mechanism, but it is interesting as a rough approximation to more complete adaptations. The ovary of the ash is built of two carpels so united as to form a pair of cavities in each of which are two ovules. Of these only one comes to maturity, and when the ovary is opened in the manner recommended in the *Practical Work*, a single seed is found together with three undeveloped ovules. Such a struggle for life among ovules is not uncommon and another instance occurs in the Sycamore.

Sycamore, Acer pseudoplatanus.

Those who have lived in the country must be familiar with the winged "seeds" of the Sycamore spinning and

FIG. 86.

FLORAL DIAGRAM OF THE SYCAMORE (*Acer pseudoplatanus*).

From Le Maout and Decaisne.

pirouetting through the air as they fall to the ground; and those who can recognise a seedling sycamore by its strap-like cotyledons can easily obtain evidence of the distance to which the "seeds" are carried. The development of these winged structures presents several points of interest.

Fig. 86 gives the floral diagram of the sycamore, in which it may be seen that the ovary has two cavities, in each of which are a pair of ovules. In fig. 87 is seen the bifid style, giving evidence that the ovary,—as in the ash,—is constructed of two carpels. The same

FIG. 87.

OVARY AND STYLE OF THE SYCAMORE.

From Le Maout and Decaisne.

figure shows that each half of the ovary is growing out laterally into what ultimately becomes the wing or flying apparatus.

Finally, as shown in fig. 88, the ovary splits longitudinally into a pair of wing-bearing capsules, in each of which one of the ovules has aborted leaving a survivor to develope into a seed. These are the bodies which fall

with a characteristic rotation, and which are not seeds, nor ovaries as in the ash, but half-fruits.

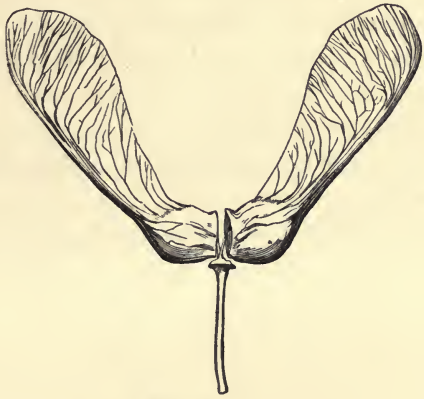


Fig. 88.

Ripe fruit of the Sycamore,
splitting into two winged compartments.
From Le Maout and Decaisne.

II. *Burrs.*

A burr is a fruit (or in some rare instances a seed) armed with hooks, by which it adheres to the hair of animals. Among English plants the most familiar instances are the common "cleavers," *i.e.* the hook-bearing fruit of a Galium, the large burrs of *Arctium lappa*, the Burdock, and the hooked fruits of Herb Bennet (*Geum urbanum*) which is included in the *Practical Work*, No. XIV. A country walk is enough to convince anyone that two of these,—cleavers and the fruit of Herb Bennet, are effective burrs.

Burrs are so common in wool that they require special

processes for their removal and form a serious inconvenience to woollen manufacturers, who give them distinctive names. The spread of certain plants from one part of Europe to another has been traced to the commercial carriage of wool. Early in the last century a species of Xanthium was introduced into Wallachia by the Russian army, being carried in the manes of the Cossack horses, which are described as being deformed by the accumulated burrs.

Herb Bennet (*Geum urbanum*) is a plant growing to a

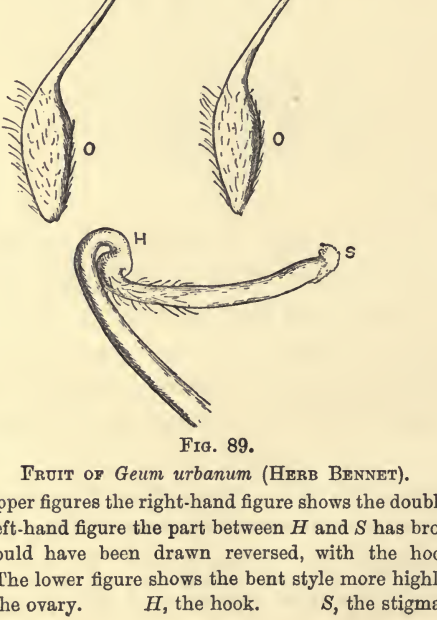


FIG. 89.

FRUIT OF *Geum urbanum* (HERB BENNET).

Of the two upper figures the right-hand figure shows the doubly bent style. In the left-hand figure the part between *H* and *S* has broken off: the fruit should have been drawn reversed, with the hook *H* to the right. The lower figure shows the bent style more highly magnified. *O*, the ovary. *H*, the hook. *S*, the stigma.

foot or two in height and bearing an inconspicuous yellow flower. In the fruiting stage the receptacle is crowned with a number of carpels each bearing a hook (*H*, fig. 89): the carpels are but loosely attached to the receptacle so that a trouser brushing against the hooks easily carries off the fruit.

The style is straight in the young flower, but with age a bayonet-like bend appears which becomes exaggerated into the curious shape shown in the lower drawing in fig. 89, as well as in the upper figure on the right. Finally the terminal limb of the crook (which ends in the stigma, *S*) breaks away and leaves a sharp, hard hook.

III. *Fruits which are eaten by animals.*

If a seed is to be distributed by passing through the intestines of an animal, two adaptations to such a mode of distribution will be met with. (1) The seed must be protected by a covering, supplied either by the seed-coats or part of the fruit, of such a nature that the seed may escape being crushed by the teeth of the animal, and may also avoid the action of the digestive secretions in the alimentary canal. (2) There must be something eatable surrounding the seed, which makes it worth while for an animal to swallow it. These characters will be studied in the cherry, the gooseberry and the pear, and it will be found that the attraction offered to animals and the protection of the seed are insured by different means and by different parts of the flower in these three plants.

Cherry (*Prunus cerasus*).

The flower of the cherry has been already described, and is shown in fig. 90.

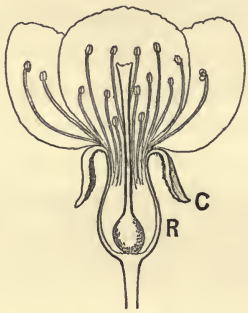


FIG. 90.

CHERRY FLOWER,

longitudinally divided.

R, the hollow receptacle. *C*, the calyx.

The ovary seated at the bottom of the cup-like receptacle is what develops into the fruit; it consists of a single carpellary leaf, on the united edges of which are borne a pair of ovules, as shown in the section of the ovary of a closely related plant, the peach (fig. 91). Only

FIG. 91.

TRANSVERSE SECTION THROUGH THE OVARY OF THE PEACH.

From Le Maout and Decaisne.

one of the ovules survives as a rule, but not infrequently both the ovules develop into seeds, when the stone contains a double kernel. As the ovary swells into the fruit, the style drops off, and the rest of the flower withers and falls away, leaving nothing but the green unripe cherry at the extremity of the flower-stalk. In this condition the noticeable external characters are the scar at the free end of the fruit where the style grew, and a longitudinal groove along one side, representing the suture, or united edges of the carpellary leaf.

Fig. 92 represents a ripe cherry divided longitudinally in the line of the suture just described. In the centre

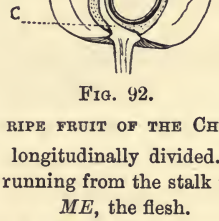


FIG. 92.

THE RIPE FRUIT OF THE CHERRY,

longitudinally divided.

C, the vascular bundles running from the stalk to the seed.

EN, the stone. *ME*, the flesh.

The skin of the cherry, the flesh and the stone are developed from the ovary-wall.

From Le Maout and Decaisne.

is seen one of the large cotyledons of the embryo, and at its upper end the minute radicle projects: surrounding the embryo is a membranous covering (the seed coat), and from the left side at the upper end of the seed is seen the delicate funicle by which the seed is attached to the wall

of the ovary. The funicle communicates by a vascular strand *C* with the stalk of the fruit, and it is through this channel that the developing seed is supplied with food from the tree. To recapitulate: the kernel of the cherry is the seed, and contains, within a soft seed coat, the embryo, whose large cotyledons fill up the whole of the cavity: the seed is attached to the inside of the stone, which is not part of the seed but is the hardened inner layer of the wall of the ovary. The rest of the ovary-wall is developed into the flesh and "skin" of the cherry. Thus the soft and sugar-containing tissue capable of yielding food, and therefore of being attractive to animals, is supplied by part of the ovary-wall, while the protective layer of hard tissue is supplied by another part of the same. In describing fruits it is found convenient to use the word *pericarp* for the part which surrounds the seeds; the terms *endocarp*, *mesocarp* and *epicarp* are also used when the pericarp is differentiated into layers of different characters. Thus in the cherry the endocarp is stony, the mesocarp fleshy and the epicarp membranous.

There are some interesting resemblances between the distribution of seeds by animals and the fertilisation of flowers by insects. In both cases the plant makes use of the movements of animals to supply its own want of locomotion. In both cases the animal is induced to serve the plant, by a bribe of food, nectar or pollen in the case of the flower, edible tissues in the case of the fruit. In both, bright colours are developed, which only appear when the flower is mature or the fruit ripe, as the case may be.

Gooseberry (Ribes grossularia).

The flower of the gooseberry (fig. 93) has already been described, the structure of the fruit may be made out by sections of the swelling ovary in the green or unripe state. The noticeable points are (1) the thickening of the wall of the ovary by the growth of tissue which ultimately forms the pulp of the ripe fruit, (2) the curious structure of the external seed-coat,—a layer of elongated

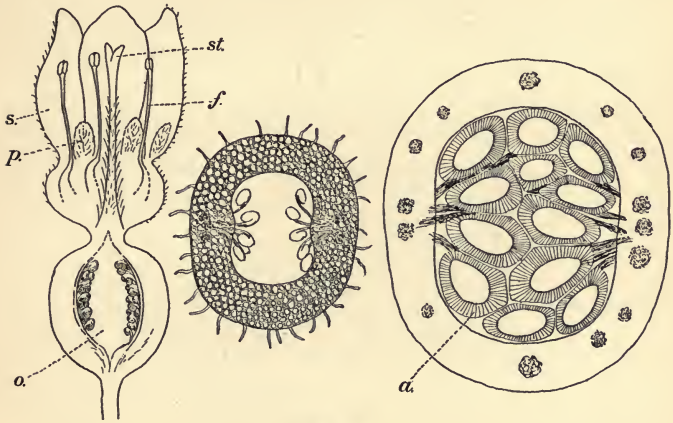


FIG. 93.

GOOSEBERRY.

On the left, the flower longitudinally divided.

o, the cavity of the ovary; *p*, petals; *s*, sepals; *f*, filaments; *st*, the bifid stigma.

In the centre, a transverse section of the ovary.

On the right, a transverse section of the ripening fruit.

a, transparent cells of the testa.

palisade-like cells, which swell up when the berry is ripe, and form part of the pulp. Thus in the gooseberry the

edible, attractive part of the fruit is formed by the ovary wall and by part of the seed-coat; the protective function is performed by the inner, hard part of the seed-coat. Small seeds, like those of the gooseberry, probably escape the teeth of animals as a result of their minuteness; in the same way, the "pips" of apples and pears escape, not by being hard enough to resist the crushing action of the teeth, but by the smoothness and slipperiness of the seed-coat.

Pear (*Pyrus communis*).

Fig. 94 shows a pear flower in which the petals have fallen and the fruit is just beginning to develope. The

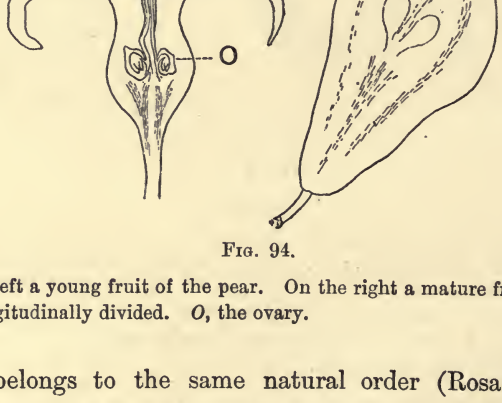


FIG. 94.

On the left a young fruit of the pear. On the right a mature fruit: both longitudinally divided. *O*, the ovary.

pear belongs to the same natural order (Rosaceæ) as the cherry and peach, and the architecture of the flower may be described as an exaggeration of the floral

structure of those plants. The wall of the cup-like receptacle shown in fig. 90 must be imagined to be greatly thickened and so much contracted that the opening is almost closed above. If within this, five carpels are placed, a model of the pear flower will have been made. The wall of the receptacle may be recognized by the stamens springing from its rim; two of the five carpels are seen at *O*, each terminating in a style which emerges at the contracted opening of the cup: an ovule is visible in each carpel. It is especially noticeable that the thick fleshy wall of the receptacle is adherent to the carpels, so that a transverse section of the mature fruit shows the seeds lying in five cavities in the flesh,—there being no space between the wall of the receptacle and the ovary: nevertheless the ovary wall is distinguishable in the membranous substance known as the core. In the mature fruit divided longitudinally as shown in fig. 94, the remains of the calyx are seen at the upper end, but the passage through which the styles emerged is practically obliterated.

In the pear and apple the edible part of the fruit is supplied by the swollen fleshy receptacle, the walls of the ovary being membranous, instead of juicy, as in the gooseberry; or half fleshy, half stony, as in the cherry. The protective function depends on the leathery coating of the seeds.

There is a good deal of evidence to show that plants are actually distributed by the seeds which have passed through the bodies of animals. The most familiar instance is supplied by the mistleto (Viscum) whose seeds are

conveyed from tree to tree by birds. The wild rose, the elder, and the hawthorn are often found in England growing on ruins or other places inaccessible except to birds; in southern Europe, too, the fig is said to spring up in crannies of steep rocks, or the faces of precipices, where doubtless the seeds have been left by birds.

APPENDIX.

PRACTICAL WORK.

No. I.

THE CELL.

I. **Yeast** (*Saccharomyces cerevisiæ*).

Put a small drop of actively growing yeast on a clean slide and cover with a clean coverslip. Examine with a high power and show on your sketch of a single cell, the cell-wall, the protoplasm and numerous vacuoles. Make sketches of budding cells, and of colonies of cells.

Run in iodine-solution and notice that the wall and protoplasm become stained brown.

II. **Spirogyra.**

i. Mount in water a few filaments of Spirogyra, and note under a low power that each filament consists of a single row of similar cells. Make a sketch of a single cell under high power, showing

a. cell-wall, sometimes covered with a layer of mucilage;

b. the spiral chlorophyll-body, showing "pyrenoids" at intervals;

c. the nucleus suspended by strands of protoplasm in the centre of the cell;

d. the nucleolus.

[Staining with iodine or with eosin may be necessary for *c* and *d*.]

ii. Draw a drop of 5 % salt solution under the coverslip with blotting-paper. Note the shrinking of the primordial utricle, *i.e.* the protoplasm lining the cell-wall, as water passes from the large central vacuole by diffusion into the salt solution. Having made a sketch of the contracted cell, draw water through as before and observe the cell reassume its turgid condition as the cell-sap returns to its former volume.

iii. Draw iodine-solution under the coverslip and note that the light zone round the pyrenoids becomes nearly black, which is due to the staining of the starch grains.

III. **Elder** (*Sambucus nigra*).

Cut a transverse section of a young stem of Elder, keeping the razor wet. Stain for a few minutes in a small quantity of iodine solution and mount in a drop of Schulze's solution placed on a clean slide. Examine with a low power, and note the pith in the centre and a similar tissue (cortex) close to the periphery. Sketch a single cell of the pith or cortex under high power, showing

a. the cell-wall, stained blue (especially well seen in the cortical cells);

b. the primordial utricle, *i.e.* the protoplasm lining the cell-wall: it is often somewhat shrunken away;

c. strands running from *b* towards *d*;

d. the nucleus, yellowish brown and very obvious;

e. the nucleolus; one or more nucleoli may be present.

IV. **Elodea.**

Mount in water a leaf of the common water-weed Elodea. Examine a single cell with a high power and note the circulation of the protoplasm. It may be necessary to wait half-an-hour or so before circulation begins.

V. **Tradescantia.**

Remove with needles a few hairs from the central parts of the flower of Spider-wort (*Tradescantia virginica* or other Tradescantia, *e.g. T. fluminensis*). Mount them in water, taking care to prevent the coverslip crushing them. Examine carefully with a high power, and note the passage of minute particles along the strands from the primordial utricle to the protoplasm surrounding the nucleus: show the direction by small arrows on your sketch.

Should this circulation of protoplasm not take place at once, slightly warming the slide as by holding it in your hand may start it.

No. II.

THE SEED AND SEEDLING. TUBERS: BULBS.

I. Seed.

i. Examine a seed of Broad Bean (*Vicia faba*) that has been soaked in water. Identify the dark coloured hilum, or point of attachment of the stalk (funicle) of the seed: near its end the position of the radicle and micropyle are easily made out; the latter by squeezing the seed and observing that water is pressed out. Remove the testa from the bean except near the radicle and hilum, and then remove this small remaining piece as a whole, and note, on the inside, the cavity in which the radicle lies; also the micropyle near which the testa gives way during germination. Split the bean and show on your sketch one cotyledon, the radicle, and the plumule.

ii. Sketch a seed of Cucurbita. The outline of the embryo is indicated on the testa, and will prevent you mistaking for the micropyle a small hole marking the position of the bundles of the stalk of the seed: in soaked seeds this hole is often filled up with pulp. Remove the seed-coat and cut off the broader end of the contents; the remaining part is easily split (from the cut end) into two parts. Show on your sketch

a. the radicle;

b. one cotyledon, showing its veins;

c. the plumule, a very small white spot at the base of the cotyledon opposite the radicle.

II. **Seedling.**

iii. Make a sketch of a germinating bean, showing the radicle emerging near the micropyle. Remove the seed-coat or testa and split open the bean longitudinally: sketch your preparation, showing on your sketch

a. the radicle;

b. the plumule;

c. the cotyledons or seed-leaves.

iv. Sketch a bean seedling, showing the ruptured seed-coat, the root and its branches, the stem and the leaves.

v. Show on your sketch of a germinating Cucurbita seed

a. seed-coat or testa;

b. radicle;

c. peg or heel which holds down one part of the seed-coat to permit the cotyledons to leave it;

d. cotyledons and the hypocotyledonary axis (hypocotyl);

e. plumule.

vi. Sketch an older seedling, showing its stem, cotyledons, leaves differing in shape from the cotyledons, and the growing apex.

III. **Tuber.**

i. Examine a tuber of the Jerusalem Artichoke (*Helianthus tuberosus*), which is a swollen stem bearing several buds. Make a sketch, showing that these buds occur singly in the axils of scale leaves.

ii. Examine the "eyes" of a potato, noticing that here two or three buds may occur in the axil of the scale leaf. Sketch a single "eye."

Cut the potato and examine under a high power a drop of the juice, which is turbid from the presence of numerous starch grains. Sketch a single starch grain showing its stratification. Let a small drop of iodine run under the coverslip and notice that the starch grains turn blue or blue-black.

A series of potatoes should be examined to show that one, two, or more shoots may arise from each eye.

Make a sketch of a seedling potato to show that the tubers are swellings of branches which arise above the cotyledons.

IV. **Bulb.**

Cut a Tulip bulb in half longitudinally. Show on your sketch of one half

a. the short stem;

b. the fleshy scales acting as storehouses of nutritive matter;

c. foliage leaves (of next year's plant);

d. the flower;

e. your preparation may also show a small bud near the flower stalk, which during the year would have developed into the following year's bulb.

[Bulbs of various ages should be examined: for instance, some while the tulips are still flowering, and others in the autumn.]

No. III.

THE ROOT.

i. Cut accurately transverse sections of a fresh Bean root, or of one that has been well hardened in alcohol, keeping your razor well moistened with spirit. Remove your sections to a watch-glass of water, taking care to keep them submerged. Mount a thin section in dilute glycerine and sketch it under the low power, showing

a. piliferous layer;

b. cortex;

c. the central cylinder.

Make a sketch of the central cylinder under high power, showing

a. the endodermis;

b. the pericycle;

c. the xylem strands;

d. the phloem strands.

ii. Cut similar sections of an older part in which lateral roots are just shown on the surface and mount as before. Make a sketch of a suitable section, showing under a low power the lateral roots, with their root caps, piercing the cortex.

iii. Sketch a Mustard seedling to show its root-hairs. They are well seen in a seedling grown in damp air, but if by becoming wetted the hairs are matted together, put the whole seedling into a glass of water and the hairs then become obvious.

Cut off the end of the root including some of the youngest hairs and mount it in a drop of water. Show on your sketch that the hairs are outgrowths of single superficial cells.

iv. Sketch a longitudinal section of the apex of a Maize root, to show the very obvious root cap.

No. IV.

THE HERBACEOUS STEM.

i. Cut transverse sections of a piece of the young stem of Sunflower (*Helianthus annuus*) or of Jerusalem Artichoke (*Helianthus tuberosus*), preserved in alcohol, keeping the razor well moistened with spirit. Soak the sections in water for a minute or two and place a thin section on a slide, add one drop of Schulze's solution, and cover in a minute or two, when stained. Sketch your section under low power, showing

a. epidermis;

b. cortex, whose deepest layer is the endodermis surrounding

c. the central cylinder, consisting of

(1) vascular bundles, separated by

(2) medullary rays, radiating out from the

(3) pith.

Sketch, under high power, a single vascular bundle, showing, towards the periphery,

a. pericycle fibres[1], each with very thick walls and a small lumen,

[1] The bast-fibres of the pericycle do not form part of the bundle; see p. 56.

b. phloem, consisting of

(1) sieve tubes or phloem vessels, mostly empty, except where sieve plates occur;

(2) much smaller companion cells filled with protoplasm;

(3) a variable amount of phloem parenchyma.

c. cambium, consisting of small brick-shaped cells.

d. xylem or wood towards the centre of the stem, and consisting of larger vessels next the cambium and occasionally packed in with wood fibres, and radiating rows of smaller vessels of the protoxylem, packed in with wood parenchyma.

Your sketch should also show the beginning of the interfascicular cambium, where a few cells in the medullary rays next the cambium have begun to divide tangentially.

[*A permanent preparation may be made by mounting in glycerine a section that has been washed in water, and enclosing the coverslip with a ring of gold size, stiff balsam, or brunswick black.*]

ii. Cut a small piece of stem in half longitudinally. Hold a piece (about $\frac{1}{4}$ inch long) in your fingers, and cut longitudinal sections that shall pass through a vascular bundle. Mount as before and show on your sketch

a. pith consisting of rectangular thin-walled cells (parenchyma);

b. spiral vessels;

c. dotted vessels;

d. cambium; elongated cells containing protoplasm and nucleus;

e. phloem vessels or sieve tubes;

f. companion cells;

g. phloem parenchyma;

h. pericycle fibres; long narrow elements with thickened walls;

i. endodermis; a single layer of cells containing starch grains;

k. cortex similar to the pith.

l. epidermis.

[If you fail to get successful sections by this method it is advisable to cut out a small piece of your tissue containing a vascular bundle, and imbed it in pith. To do so, slit a piece of Elder pith longitudinally with a sharp knife and place your tissue in the slit so that the radius of the stem passing through the bundle is level with the pith edge. Pare off the pith, leaving only a small area round the imbedded tissue, and cut sections of the tissue and of the imbedding pith together: the pith is easily separated on washing the sections from the razor into a watch-glass of water. Do not use your section razor for slitting or paring pith, which should be done with the older razor used for rough work.]

No. V.

THE ARBOREAL STEM.

i. Cut transverse sections of an Oak twig of the current year. Mount in glycerine and examine with a low power. Show on your sketch

a. epidermis;

b. cortex;

c. vascular bundles forming an irregular ring;

d. pith;

e. medullary rays.

Sketch a single bundle, shewing its xylem, phloem and cambium, and compare your sketch with that of a bundle in the Sunflower, noting that in the Oak there is a large amount of thick-walled wood fibre.

ii. Examine a transverse section of the stem of an Oak seedling, and shew on your sketch that the bundles do not yet form a ring, but are isolated somewhat as in Sunflower.

iii. Examine an older stem with a simple lens. Cut the surface clean with the razor reserved for rough work. Make a sketch of the surface as seen with the simple lens, shewing the annual rings of wood and the medullary rays. The larger vessels in the spring wood are easily made out.

Peel the stem and from a piece of the peeled wood cut transverse sections which must be mounted in dilute glycerine. Shew on your sketch the annual rings due to the approximation of the denser autumn wood with the succeeding spring wood.

iv. Cut tangential longitudinal sections of a small piece of the same stem, and mount in dilute glycerine. Make a sketch of your section, shewing the medullary rays as lenticular groups of cells, well seen in the harder parts (fibres) of the wood between those lighter tracts which are the large dotted vessels.

v. With a knife split the remnant of your stem longitudinally into quarters. Then cut radial longitudinal

sections of one quarter. [You should attempt to cut a very small piece only.] Shew on your sketch the medullary rays as strands of from two to ten or more rows of cells running from the centre outwards across the fibres and dotted vessels. Your section may possibly shew also the spiral vessels next the pith.

vi. Carefully examine specimens of old stems of various sorts and identify the medullary rays (silver grain), and the annual rings as seen in bulk.

No. VI.

PHLOEM AND CORK.

i. Cut accurately transverse sections of a small piece of the bark of the Oak stem and of the wood attached to it. Shew on your sketch drawn under low power, but using the high power where necessary,

a. soft phloem, consisting of sieve tubes and companion cells;

b. hard phloem, isolated small patches of white, very thick-walled elements;

c. numerous cluster-crystals of calcium oxalate, more numerous in the soft phloem;

d. small groups of thick-walled, pitted, sclerenchymatous cells;

e. primary cortex;

f. cork on the outside; immediately beneath it the cells are flattened and brick-shaped: these constitute the

cork cambium or phellogen, for the structure of which see below;

g. phelloderm; oval, fairly thick-walled cells next below the phellogen, and next to the primary cortex.

ii. Cut longitudinal radial sections of the same material. Identify the above tissues; the phloem fibres now appear as white thick-walled elements occurring in strands running between groups of soft phloem. Cubical crystals arranged in longitudinal rows are very numerous bordering the groups of fibres; notice too the cluster-crystals mentioned above. Scattered groups of thick-walled pitted cells—sclerenchyma—also occur.

iii. Examine a twig of the Hedge Maple (*Acer campestre*). In the lower, and older, part notice the furrows in the cork due to the cracking caused by growth. Proceeding towards the apex these furrows become less obvious until in the younger part they disappear.

A transverse section at the younger part should be carefully compared with one taken lower down. In your sketch of the younger part shew, proceeding inwards,

a. the epidermis;

b. cork;

c. the phellogen.

Sketch the larger section to shew the furrows in the cork.

iv. In a transverse section of a young Beech stem examine carefully the phellogen. Note that the superficial layer of the cortical cells begins to divide, producing a cork cell towards the outside while the inner cell continues to divide, thus constituting the phellogen or cork cambium

No. VII.

THE LEAF.

i. Imbed in pith a piece of Hellebore leaf preserved in alcohol: cut sections at right angles to the midrib of the leaf and mount in dilute glycerine. Shew on your sketch:—

a. epidermis of the upper surface; the cells contain protoplasm and a nucleus but no chlorophyll-corpuscles;

b. palisade cells of the mesophyll;

c. spongy tissue of the mesophyll;

d. epidermis of the lower surface similar to *a.*, but with stomata whose guard cells contain chloroplasts.

ii. Strip off a piece of the lower epidermis of a fresh living leaf and mount in water. Shew on your sketch:—

a. epidermal cells with sinuous outlines, containing no chloroplasts;

b. stomata, each with two kidney-shaped guard cells, containing chloroplasts.

iii. Place the lamina of a living leaf of *Ranunculus ficaria, Limnocharis Humboldtii,* or *Arum maculatum* in a glass of water; then suck at the end of the leaf-stalk (petiole) watching the lower surface of the lamina. As the sucking proceeds, the leaf appears sodden, the darkening in colour being due to the entrance of water into the intercellular spaces.

iv. Examine a branch of Groundsel (*Senecio vulgaris*) to observe the phyllotaxis or order of succession of

leaves on the stem. Count (*a*) the number of leaves you pass and (*b*) how many times you pass round the stem before a leaf is found whose position is exactly above that from which you began.

v. Examine a branch of Horse-chestnut (*Æsculus hippocastanum*). Shew on your sketch the scars of the leaves and of the vessels of their bundles; also the scars of the scale-leaves at the base of each year's shoot, which scales at one time covered the winter bud.

vi. Cut and sketch a longitudinal section of the swollen base of a leaf-stalk of Poplar and of the stem to which it is attached, shewing

a. stem bundles;

b. leaf bundles;

c. outline (epidermis) of stem and petiole;

d. the absciss layer across the swollen base of the petiole which permits the leaf to fall, and forms a layer of cork covering the scar made by the loss of the leaf.

No. VIII.

REPRODUCTION.

I. Pleurococcus.

i. Mount in water a small quantity of the green powder found on trunks of trees or damp wood, and examine it with the high power. Make sketches to shew:—

a. a single cell; its cell-wall, and the contained protoplasm coloured green;

b. cells in various stages of division.

ii. Mount a few cells in Schulze's solution and notice that the cell-wall is stained blue (cellulose).

II. **Spirogyra.**

iii. Carefully examine some Spirogyra to find conjugating filaments, and make sketches of the various stages of conjugation, viz.:—

a. the formation of protuberances on cells of contiguous filaments;

b. their approach and impact, and the concentration of the cell contents;

c. the flattening of the wall now common to the two protuberances, and their bulging at the point of contact. The cell protoplasm is now passing into the protuberances.

d. the passage of the protoplasm of one cell through a hole produced by the solution of a part of the dividing wall of the protuberances, and the consequent formation of the zygospore.

e. the thickening of the wall of the zygospore. This however may not be shewn in material examined early in the year, *i.e.* before June.

III. **Mucor.**

iv. Mount in water a small piece of Mucor grown on gelatine. Sketch a portion of a young hypha, shewing the cell-wall, and the protoplasm containing numerous vacuoles; these are smaller towards the tip, where indeed they may be absent.

v. Make a sketch of young sporangia, some contain-

ing developing spores and some before this stage, just shewing the columella.

vi. Sketch a sporangium that has burst, shewing

a. the columella, to which some spores may be found adhering;

b. the remains of the wall of the sporangium at the base of the columella: *b* is known as the *collar*.

vii. A series of sketches should be made from specimens shewing stages in the formation of the zygospore by the conjugation of branches from the hyphæ.

No. IX.

THE FERN.

i. Make a sketch of a part of a plant of *Pteris aquilina*, shewing

a. the rhizome;

b. its growing point;

c. leaves in various stages of growth;

d. roots.

ii. Make a sketch of the clean-cut surface of a piece of the rhizome, shewing

a. external brown tissue consisting of the epidermis and the subjacent hypodermal sclerenchyma;

b. the two lateral lines where *a.* is very thin, the sclerenchyma being absent, and *c.* comes to the surface;

c. the soft parenchyma;

d. strands of brown sclerenchymatous tissue; two large strands, and many small ones appearing as dots;

e. the vascular bundles, of various size.

iii. Cut a transverse section of a piece of rhizome preserved in alcohol, and mount it in glycerine. Examine the parts mentioned above, first with the low and then with the high power. Make a sketch of a single vascular bundle under the low power, shewing the endodermis, the phloem, and the xylem.

Sketch the bundle under the high power, shewing

a. the brown endodermis;

b. the colourless pericycle, often containing numerous small starch grains;

c. the protophloem, consisting of flattened cells;

d. the phloem vessels (sieve tubes) and the phloem parenchyma;

e. the yellow xylem.

iv. Cut a longitudinal section of a small piece of the rhizome and mount in glycerine. Examine first with the low power and then make sketches under the high power of

a. the peripheral sclerenchyma, consisting of short brown-walled cells;

b. the soft parenchyma — thin-walled rectangular cells containing starch grains;

c. the sclerenchymatous tissue made up of long, narrow, brown, thick-walled cells;

d. the bundle-sheath;

e. the pericycle;

f. sieve-tubes with lateral sieve-plates;

g. scalariform vessels of the xylem. Your section may possibly also shew spiral vessels of the protoxylem, though they will be more easily seen in the macerated material.

v. Spread out gently in a drop of water a small piece of Pteris rhizome that has been macerated, and identify the various tissue elements already sketched from your sections, observing especially sclerenchymatous cells, sieve-tubes with irregular reticulate thickening, and the spiral and scalariform vessels of the xylem.

No. X.

THE REPRODUCTION OF THE FERN.

i. Cut a section of the leaf of Pteris preserved in alcohol and mount it in glycerine. Sketch your section under the low power, shewing the numerous stalked sporangia arising from the placenta, the whole sorus being covered by the recurved margin of the leaf.

ii. Cut a section of the leaf of Aspidium, passing through the centre of one of the numerous white kidney-shaped bodies, each of which is a sorus covered by its indusium. Shew on your sketch stalked sporangia borne on a placenta and covered by the umbrella-shaped indusium.

iii. Place a few sporangia from the wetted sorus of *Polypodium aureum* on a slide, in the smallest possible

drop of water, and cover with a coverslip. Allow a drop of strong glycerine to run in under the coverslip while you watch the sporangia under the low power. Note that the sporangia open as the glycerine reaches them. Make a sketch under high power of a ripe sporangium, shewing the annulus and ripe spores; and of a sporangium after it has opened.

iv. Find under the low power and examine under the high power some germinating fern spores mounted in a drop of water. Make a sketch of a single spore and its prothallus, shewing

a. the spore;

b. the rhizoids;

c. the prothallus;

d. its antheridia; antherozoids may possibly be found in your preparations.

v. Mount a small prothallus of a fern in a drop of water, with its lower surface uppermost. Shew, on a sketch under low power, the antheridia and archegonia, also the root hairs or rhizoids, all borne on the thicker central part or cushion.

vi. Examine a longitudinal section of the cushion of a prothallus bearing archegonia. Make a sketch under the high power, shewing

a. the neck composed of several tiers of cells and standing out beyond the lower surface of the prothallus;

b. the large cell in the lower part and imbedded in the prothallus—the egg-cell.

vii. Sketch an old prothallus of a fern, shewing on your sketch

a. the prothallus;

b. the young sporophyte growing from its lower surface.

No. XI.

THE FLOWER.

i. Examine a flower of Ranunculus, noting:—

a. calyx of five sepals;

b. corolla of five petals;

c. androecium of numerous stamens;

d. gynœcium of numerous free carpels.

Cut the flower in half longitudinally and make a sketch of the section shewing the relative position of the parts.

Sketch a single stamen shewing the lines of dehiscence of the anther;

ii. Sketch the papilionaceous flower of the Bean, shewing the calyx and corolla.

Dissect the flower and make sketches of:—

a. calyx of five sepals joined together;

b. the petals of the corolla, viz.:

1. the standard or vexillum,
2. one of the two wings or alæ,
3. two petals joined together to form the keel or carina which covers the essential organs.

c. androecium, consisting of ten stamens, of which nine are joined together by their filaments, forming a trough enclosing the ovary; the tenth stamen roofs in the trough.

d. gynœcium, consisting of one carpel; the swollen basal part or pod is the ovary, the elongated portion (the style) ends in the stigma.

Draw the floral diagram.

iii. Cut transverse sections of a flower bud of *Caltha palustris* (the Marsh Marigold) preserved in alcohol. Push the sections of anthers from the razor direct into a drop of glycerine on a clean slide, and cover. Select under the low power a thin section for examination under the high power, and shew on your sketch

a. the four pollen sacs which eventually fuse into the two lobes of the ripe anther; [Sketch various stages.]

b. the fibrous layer under the epidermis, incomplete at the point where fusion of the two pollen sacs of each side commences,—that is, on the line of dehiscence;

c. the young pollen grains;

d. the connective.

No. XII.

THE FLOWER (*continued*)—DICHOGAMY.

i. Examine a Dog-Daisy (*Chrysanthemum leucanthemum*), noting:—

a. involucre of green bracts;

b. white ray florets;

c. yellow disc florets.

Divide the daisy into two by cutting upwards along the middle of the stalk. Sketch the section thus displayed, shewing

a. receptacle;

b. bracts;

c. ray florets;

d. disc florets.

[The "flower" is in reality an inflorescence consisting of numerous flowers borne on a swollen and more or less flattened receptacle.]

ii. Sketch an isolated ray floret, shewing

a. corolla;

b. bifid stigma;

c. ovary.

iii. Shew on a sketch of an isolated disc floret

a. ovary;

b. corolla with five lobes;

c. anthers, forming a tube standing above the corolla; from the middle of this tube the stigma emerges: it afterwards opens so as to be obviously bifid, as may be seen by comparing various florets. Slit open the corolla with a needle and shew on a sketch that, while the filaments are free, the anthers are all joined together (syngenesious). Now slit open the tube of anthers and shew that the style passes up inside the tube, thus sweeping out the pollen which has been shed from the anthers, which in this case open internally.

To understand the adaptation for cross-fertilisation, disc florets of various ages must be compared.

[A comparative examination should be made of a floret of Centaurea, Dandelion, or Groundsel, where the calyx is very obvious, consisting of a number of hairs, and constituting the "pappus," which afterwards forms the "clocks" of the dandelion and groundsel.]

iv. Mount a few pollen grains of the Dog-Daisy in a drop of water or spirit and examine with a high power, shewing on your sketch the spiny outer coat.

v. Make a sketch of pollen grains which have been allowed to germinate in a solution of sugar, shewing the pollen grain and the pollen tube it has put forth.

vi. Examine a spike of Plantain (*Plantago*), noting that the flowers towards the apex have their long stigmas ripe though no anthers are visible, while lower down the anthers are mature and shedding their pollen. Make sketches to illustrate this state of things (dichogamy).

vii. Examine flowers of either Silene, Tropæolum, or Sweet William, noting that in the younger flowers the anthers are mature, but the stigmas are not yet ready for pollination, while the older ones have mature styles. The flower is dichogamous, but is *protandrous*, not *protogynous* like the Plantain.

No. XIII.

THE SEED.

i. Make a sketch of a longitudinal section of the stigma of Œnothera, the Evening Primrose, shewing

a. triangular pollen grains on the margin of the section;

b. pollen tubes growing from them and piercing the tissues of the style on their way towards the ovules in the ovary.

ii. Cut transverse sections of open flowers of *Caltha palustris* (Marsh Marigold) and wash off the sections of carpels from the razor into a watch-glass of water. Mount in dilute glycerine a section which contains ovules. Shew in your sketch, under a low power:—

a. the carpel with its midrib;

b. the ovule or ovules, attached by stalks (funicles) to the margins of the carpel. Note that the ovules are anatropous;

c. the embryo-sac.

Sketch the contents of the embryo-sac under high power, shewing

d. the egg apparatus, consisting of two synergidæ and an egg-cell;

e. the antipodal cells;

f. the secondary nucleus of the embryo-sac.

iii. Examine the fruits of Capsella (Shepherd's purse) and pull off the ovary wall from some of the youngest. Numerous ovules spring from the margins of a central dividing wall. Remove with needles some of the ovules to a watch-glass containing a little potash solution, and after soaking for five or ten minutes (until they are almost transparent) mount them in a drop of glycerine or water on a slide, giving one gentle but sudden tap to the coverslip to burst the ovule and force out the embryo. In this way various stages in the development of the embryo may be obtained, and should be carefully sketched. Use a high power for very early stages, and a low power when the cotyledons can be easily identified.

Remove one of the young seeds from the oldest available fruit and carefully open the seed-coats (testa) with needles under the dissecting microscope. Make a sketch of the embryo thus set free, shewing its radicle and cotyledons. The plumule may possibly also be identified, but it is very small and inconspicuous.

iv. Cut transverse sections of a young fruit of Gooseberry (*Ribes grossularia*), mount in glycerine and examine with the low power. Sketch your section, shewing:—

a. ovary formed of two carpels joined together;

b. numerous hairs on its outer surface;

c. vascular bundles and very large cells occurring in the tissues of the carpels;

d. several anatropous ovules borne on the two placentas.

No. XIV.

THE FRUIT.

I. **Cherry** (*Prunus cerasus*)

i. Examine a cherry flower, noting the five sepals, five petals and numerous stamens arising from the hollow receptacle. Lay open the flower by slitting it down one side with your knife. Shew on your sketch the insertion of sepals, petals, and stamens on the receptacle, and the single ovary at its base. Cut transverse sections of the ovary and shew on your sketch the two ovules contained in it.

ii. Examine the young Cherry fruit preserved in alcohol, and note the point of attachment of the stalk, the scar of the style, and the longitudinal groove representing the suture of the single carpel. Cut the cherry in half along this groove and show on your sketch

a. the part which forms the flesh of a ripe cherry;

b. stone (closely adherent to *a.*): this you will find now becoming hard beneath the scar of the style;

(*a* and *b* together constitute the pericarp).

c. the attachment of the ovule to one side of the stone, near the stigmatic end, and the bundles running up from the stalk to the ovule; note that only a single ovule comes to maturity;

d. the nucellus and endosperm.

iii. Halve a ripe cherry and identify the parts already seen, noting especially the hard stone which on being broken is found to contain one seed.

II. **Pear** (*Pyrus communis*).

iv. In a Pear flower whose petals have fallen note the five sepals, numerous stamens, five styles which arise from the centre of the flower, and the swollen receptacle beneath the sepals.

v. Cut longitudinal sections of the flower till the axial section is reached and mount this in dilute glycerine. Make a sketch of the remaining half under the simple lens, showing:

a. hollow receptacle;

b. sepals;

c. stamens;

d. styles;

e. ovules.

Make out under the low power the same parts as far as you can in your section and show on the sketch of your section:

f. the ovary;

g. the lateral attachment of the ovules.

vi. The median longitudinal section of a ripe pear should also be examined and a series of ripening pears sketched to show stages in the development of the fruit.

III. **Gooseberry** (*Ribes grossularia*).

vii. Cut transverse sections of a fresh Gooseberry and compare it with your sketch of the preceding lesson. Show on your sketch under a simple lens or low power that the cavity of the ovary is now entirely filled with the young seeds whose stalks are elongated and whose testas have a layer of long transparent cells constituting part of the pulp of the ripe fruit. (The remainder of the pulp is made up by the inner loose tissues of the wall of the ovary.)

IV. **Ash** (*Fraxinus excelsior*).

viii. Examine a fruit of Ash, noting the thin flat expansion of the free end. With your knife cut through the basal part about a quarter of an inch from the stalk; you will find it is hollow. Pass the point only of your knife along the edge for about a quarter of an inch and pull the two valves (each consisting of the united halves of two carpels) asunder so far as to expose the ovary. Show on your sketch the two ovules in each loculus, of which three

are undeveloped and the remaining large ovule is at the end of a twisted stalk.

V. **Sycamore** (*Acer pseudoplatanus*).

ix. Examine and sketch a half-fruit of Sycamore, noting the wing and the swollen part containing the single seed.

x. A careful drawing should be made of a transverse section of the ovary of the Sycamore, which shows well the two ovules in each loculus, of which one only persists, the other remaining undeveloped.

VI. **Dandelion** (*Taraxacum dens-leonis*).

xi. Examine a floret from the Dandelion and show on your sketch the pappus representing the calyx. This pappus forms a float, for the purpose of seed distribution by wind. Examine a head of fruits of Tragopogon, which resembles the "clock" of the Dandelion.

VII. **Herb Bennet** (*Geum urbanum*).

xii. Sketch the fruit of Geum in various stages, showing the persistent calyx, the stigmas and hooks. Make a careful examination with the simple lens of the development of the hooks; the stigma breaking off at the bend, leaves a hook which serves to distribute the seeds, by becoming attached to animals.

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